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THE NEW LUMINOUS STANDARD

by G. HELLER.

535.241.42

Beginning January the 1st, 1940, the international candle power is to be replaced by a new unit which is based upon the radiation of a black body at the temperature of melting platinum. In this article the considerations are examined which have led to the development of the new light unit. In conclusion the properties of the light of the "new candle" are discussed in detail.

Introduction

When towards the end of the last century, chiefly due to the invention of the carbon filament lamp, the use of electric light was becoming more and more general, the problem of expressing the light produced in numbers also became more and more urgent. It will be obvious that this could be done by comparing the intensity of the light produced with that of a carefully standardized source of light. This luminous standard took the form of a flame, fed with some kind of combustible liquid. It was found possible to render the light intensity of such a light source reproducible with sufficient accuracy by choosing the diameter of the wick, the chemical composition of the fuel, the height of the flame and the direction of observation according to definite specifications. In this way the so-called Hefner candle was established in 1896 in Germany as unit of light intensity. In other countries similar standard lamps were adopted, such as the pentane lamp, the spermaceti candle and the Carcel lamp, and soon attempts were made to reach agreement on an international standard of light intensity.

In these attempts it was found that none of the standard flames could be considered absolutely satisfactory. The use of open flames with precisely determined radiation properties requires very elaborate precautions as to the condition of the atmosphere. Moreover the colour of the light usually deviates very much from that of the sources to be measured (electric lamps), which makes photometric comparison difficult. This difficulty early led to the construction of auxiliary standards for practical use in the form of carbon filament lamps. It was then found that these auxiliary standards could be compared with each other with much more accuracy than with the various primary standards. This led finally to the use of a set of these standard lamps, which had been compared with the national standards in the different countries, as a basis for the establishment of the international unit of light intensity. In 1909 the unit of light intensity so defined was adopted by France, England and the United States, while Germany, in agreement with these countries, established the fact that the Hefner candle was equal to $^9/_{10}$ of an "international candle" (IC).

Objections to the international light unit

Although the fixing of a light unit by means of a set of electric lamps makes possible very simple and accurate measurement, there are serious objections to this method in principle. The most important requirement made of a standard is that it either be absolutely constant or that it be possible to reproduce it with the necessary precision at any moment. Neither of these two conditions is fulfilled in the case of the light unit in question: the light intensity of an electric lamp decreases, although very slowly, in the course of time due to the evaporation of the filament and the blackening of the bulb; it is also impossible — at least until now — to standardize the manufacture of an electric lamp to such a point that a lamp made according to the specifications shall always have the same light intensity within the accuracy of measurement.

In order to avoid the decrease in light intensity, much use is made of secondary and tertiary standards, and the primary standard is used as little as possible. Nevertheless the situation is far from satisfactory. The various derived standards are not only carbon filament lamps, but also tungsten filament lamps. The latter burn at a considerably higher temperature, and therefore have a different spectral composition of light. This makes a photometric comparison of the different standards so difficult that there still exists some doubt as to the intensities of the various standard lamps.

The difficulties are further increased when the different standard electric lamps have to be compared not only with each other, but also with the Hefner candle, which still remained the basis of photometry in certain countries. It was discovered that different values result for the numerical ratio between the Hefner candle and the international candle, according as a carbon filament lamp or a tungsten filament lamp are used as standard of the international candle. The difference amounts to about 5 per cent: with the help of a carbon filament standard the ratio mentioned is:

$$\text{Intern. candle} : \text{Hefner candle} = 1.11,$$

while the tungsten filament lamps give values between 1.14 and 1.17, depending on their colour temperature. It is clear that this discrepancy considerably decreases the comparability of measurements obtained in Hefner units and those in international units ¹).

The difficulties which are encountered in the comparison of the Hefner candle with the international candle must be ascribed to the fact that in using the Hefner candle one is compelled to work with extremely low brightnesses of the photometer screen. Every measurement of intensity is based upon an illumination of the photometer screen by the light source investigated, and a calculation of the intensity by means of the inverse square law. This law will, however, not apply at small distances of the Hefner candle because the light is produced not only at the surface of the flame but partially also in the interior, so that the distance will differ by several millimetres for different parts of the radiation. In order to obviate this difficulty the candle must be placed far enough away from the photometer screen, for instance 1 m. The intensity of illumination is then 1 lux, a value with which it is no longer possible to apply the methods of photometry with great accuracy, and with which moreover an appreciable Purkinje effect already appears ²).

In order to make the influence of this effect clear, we shall suppose that two photometer screens are illuminated by a tungsten filament lamp and a carbon lamp respectively, with an intensity of about 25 lux (this is a suitable value for photometry), and that the photometer is adjusted for equal brightnesses of the two screens. If we now decrease both light intensities by a factor 25, for instance, by making the distances from the sources five times as great, we will observe that the brightnesses of the photometer screens are no longer equal, but that that of the white photometer screen (tungsten filament) is several per cent higher than that of the yellow screen (carbon filament). The measured ratio between the light intensities of the yellow lamp and the white lamp thus changes in photometry with low intensities of illumination in favour of the white lamp, and it is therefore clear that the latter will give a larger number of Hefner candle powers per international candle power than the former.

The new luminous standard

In order to overcome the above-mentioned difficulties an attempt was made to develop a light unit which combines the advantages of the Hefner candle with those of the international candle. On the one hand therefore the new unit could not be fixed by an existing set of lamps, but it had to be able to be made in a reproducible way according to definite specifications. On the other hand it was desirable for the sake of avoiding photometric difficulties that the new light source should have a considerably greater brightness and also a higher colour temperature than the Hefner candle.

As early as 1879 Violle had suggested a light source which it was hoped would satisfy these requirements. Violle proposed as light unit the intensity of the light radiated by 1 sq.cm of a surface of glowing platinum at the temperature at which platinum is just melting. One twentieth part of this light intensity, which corresponds approximately to the international candle power, was actually considered as the primary light standard in France from 1889 until 1909. After that date this standard light source was, how-

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¹) Although in principle the ratio IC : HK should be able to be fixed absolutely, no one has ever succeeded in removing these discrepancies. The seriousness of this difficulty may be seen from the fact that the I.C.I. in 1928 was forced to recommend different values for the ratio between the international candle and the Hefner candle, depending on the colour temperature, namely:

2000°	1.11
2360°	1.145
2600°	1.17.

²) This effect is discussed in detail in Philips techn. Rev. 1, 142, 1936.

ever, discarded because the accuracy with which it could be reproduced was found not to come up to expectation.

The reason is that the radiation of a glowing body is determined not only by its temperature but also by the reflective properties of its surface. Experience showed that by carefully freeing platinum of impurities its melting point could be reproduced to within less than one degree. The reflective properties of the surface, however, even in the case of the most carefully purified material, were not found to be so constant that the light source could be reproduced with the desired accuracy.

There is, however, another method of obtaining a surface with known radiation properties: the body to be heated is given such a form that part of its surface possesses no reflective power at all. Such a "black body" can be realized by a tube which is so narrow and deep that light entering it cannot escape through the opening. Upon heating the tube to a given temperature the absolutely "black" opening of such a tube radiates more intensely than any material surface, possessing certain reflection, and there is moreover the advantage that the intensity of this black body radiation and the variation of the intensity as a function of the wave length is independent of any possible irregularities in the radiating surface of the tube.

It has been found experimentally that the brightness which a black body assumes at the temperature of melting platinum can be reproduced with the desired accuracy, and that this light source is suitable for precise photometric measurements. After these investigations had been concluded it was decided in 1937 [3]) to introduce a "new luminous standard" as unit of light intensity beginning with January the 1st 1940, and that this unit should be defined in such a way that a black body at the temperature of melting platinum has a brightness of 60 new candles per square centimetre. This new light unit has been adopted by all the countries which have until now used either the Hefner candle or the international candle.

Construction of the new luminous standard

Fig. 1 shows the arrangement used by the "Bureau of Standards" for the realization of the new candle. A crucible of thorium oxide is filled with pure platinum. The black radiator is situated at the axis of the platinum ingot and takes the form of a tube also made of thorium oxide. For the purpose of better heat insulation the crucible is placed in a larger container filled with powdered thorium oxide.

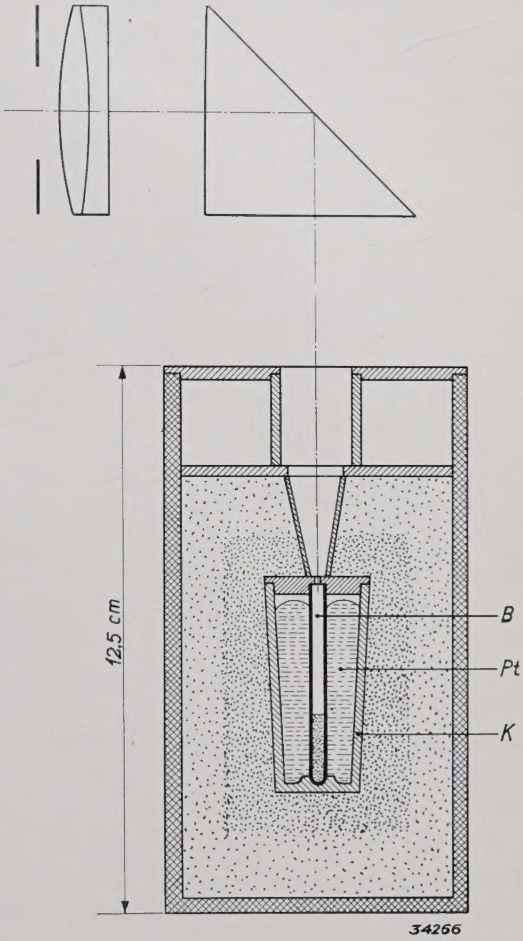

Fig. 1. Experimental arrangement of the "new candle". *B* tube of thorium oxide (black body), *K* crucible of thorium oxide, P_t platinum.

The platinum is heated by means of high-frequency eddy currents which are generated in the platinum itself by means of an induction coil. When the platinum is melted a strong circulation is maintained by the electrodynamic forces occurring in the liquid [4]), which promotes uniformity in the temperature distribution. By means of a prism and a lens the light emerging in a vertical direction from the tube is transformed into a horizontal beam. The intensity of this beam can be compared with that of the substandard to be calibrated by the well known methods of photometry.

Properties of the new luminous standard

The very careful measurements of the Bureau of Standards (U.S.A.), the National Physical Laboratory (England), the Physikalisch-Technische

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[3]) Rev. Gén. d'El. XLII, 5, p. 129. Comité internationale des Poids et Mesures, Réunion de juin 1937. Unités photometriques: Résolution I.

[4]) This subject was treated in detail in an article about a high-frequency furnace: Philips techn. Rev. 1, 53, 1936.

Reichsanstalt (Germany) and G. Ribaud (France) found, in good mutual agreement, a value of the brightness of the black body at the temperature of melting platinum of

58.8 IC/cm², and 65.3 HK/cm²,

which are equivalent when the ratio IC : HK is considered equal to 1.11.

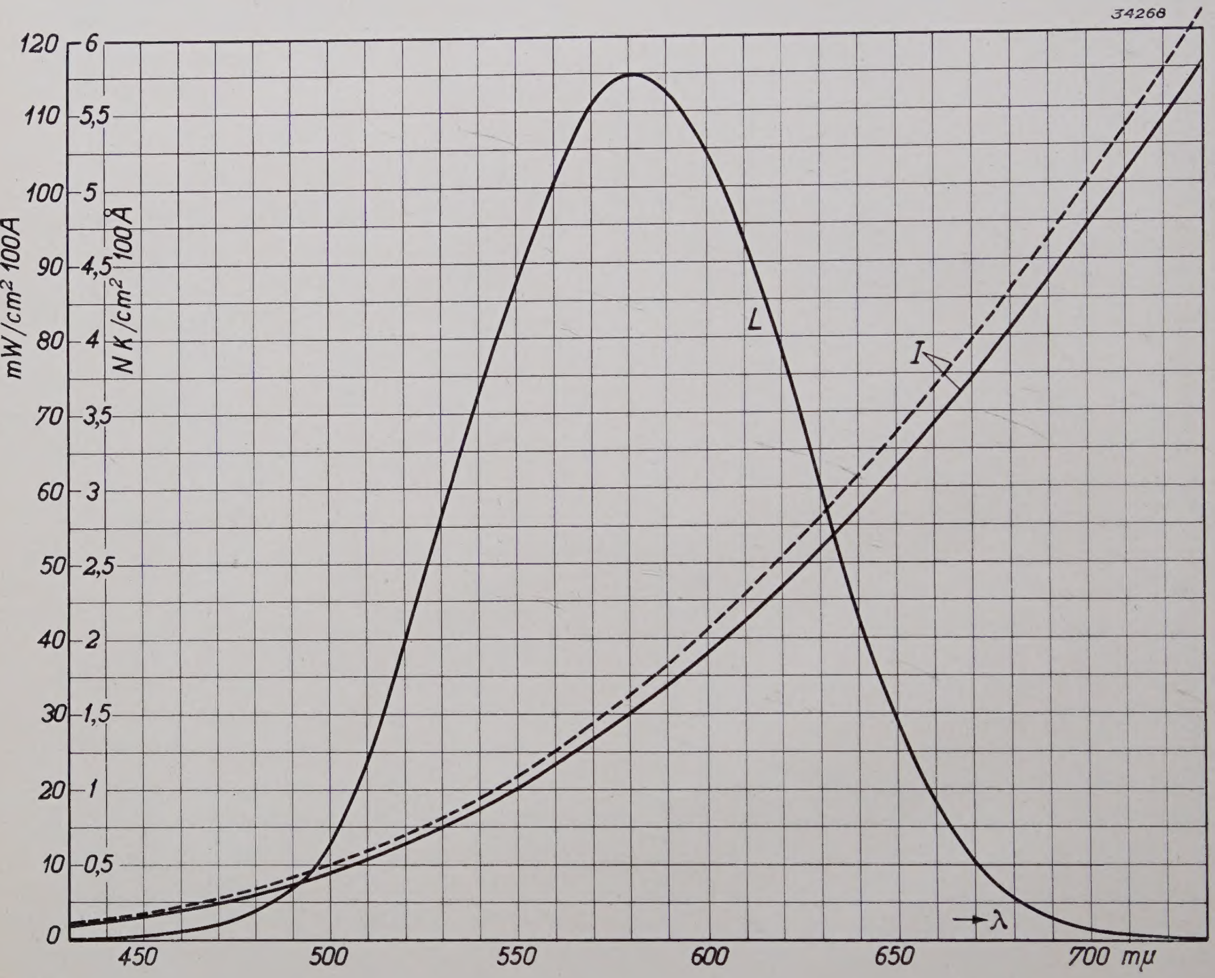

Fig. 2. Radiation intensity I in mW per cm² per 100 Å and light intensity L in new candles per cm² per 100 Å of a black body at the temperature of melting platinum as a function of the wave length. In calculating the full line curves (see equation (1)) we used the constants $c_1 = 3.743 \times 10^{-5}$, $c_2 = 1.439$, $T = 2041.3$, while the broken line curves were calculated with the constants $c_1 = 3.699 \times 10^{-5}$, $c_2 = 1.432$, $T = 2046.6$.

Since by definition this brightness corresponds to 60 new candles per sq.cm, it is clear that the intensity of the new candle lies between that of the Hefner candle and that of the international candle [5]).

The colour of the light from the new candle corresponds approximately to that of the carbon filament standard lamps for the international candle, and it is due to this circumstance that the new candle and the international candle could be compared to each other down to one part in a thousand.

The spectral light distribution of the new candle can be found by calculating the intensity distribution by means of Planck's radiation formula, and then multiplying the intensity at each wave length by the corresponding relative luminosity factor. For this purpose several experimentally determined constants must be accurately known, namely the melting temperature of the platinum T_p and the constants c_1 and c_2 in Planck's formula:

$$I_\lambda \, \mathrm{d}\lambda = \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1} \, \mathrm{d}\lambda, \quad . \quad . \quad . \quad . \quad (1)$$

which indicates the radiation intensity I_λ of a black body having the temperature T in the wave range between λ and $\lambda + \mathrm{d}\lambda$.

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[5]) As for Philips lamps, beginning with Jan. 1st 1940 the new luminous standard will be adopted as well as the appropriate new photometric method of bridging the colour difference between the standard light source and the electric lamp. The result of this change will be that there will be little or no change in the intensity of the lamps.

Quite recently some doubt has arisen as to the correctness of the values of these constants accepted in the past [6]). While on the basis of investigations carried out before about 1935 the following values were considered most probable:

$$c_2 = 1.432,\ T_p = 2046.6\ ^\circ\mathrm{K},$$

the latest investigations give the results:

$$c_2 = 1.439,\ T_p = 2041.3\ ^\circ\mathrm{K}.$$

Although the change in the constants only amounts to several parts in a thousand, the theoretical aspect of the spectral intensity distribution is hereby very considerably altered. Further consideration of equation (1) shows that the intensity in the region of visible wave lengths varies approximately with the tenth power of T/c_2. Since T_p has become about 0.25 per cent lower, while the constant c_2 has increased 0.5 per cent, Planck's formula now gives about 7.5 per cent lower values in the visible region than formerly when the old values of the constants were used. A small change also occurs in the value of c_1, which, however, only feably affected the results.

The difference is clearly visible in *fig. 2* where the spectral intensity I is plotted in mW per sq.cm. per 100 Å as a function of the wave length. The broken line refers to the former values of the constants c_2 and T_p; the continuous line is calculated with the new values of the constants. If now we use the spectral intensities to compute the light distribution curve (new candles per sq.cm per 100 Å), which is given by $L(\lambda)$ in fig. 2, we note that the change of constants only has a very small influence. The light distribution curve is found by multiplying the spectral distribution of the intensity (new constants) by the international relative luminosity factors, and in addition by a factor such that the total light intensity becomes equal to 60 candle powers. Since the total light intensity is fixed by means of this factor, the influence of a change in the constants c_2 and T_p on the light intensity curve is much smaller than was to be expected from the intensity curve; practically the same shape is found with the new as with the old values of the constants.

This influence is much greater in the spectral variation of the efficiency given in *fig. 3* as calculated from the data used in fig. 2. The shape of the curve naturally corresponds with that of the international relative luminosity curve. The broken-line curve (old constants) has a maximum of 636 new lumens/watt (624 international lumens per watt) which agrees very well with the values of the so-called mechanical equivalents of light generally given in the literature. With the new constants, however, one finds a maximum of 688 new lm/W (675 int. lm/W), and this high value is difficult to reconcile with the results of other determinations of the light yield. Further investigation on this point is thus called for.

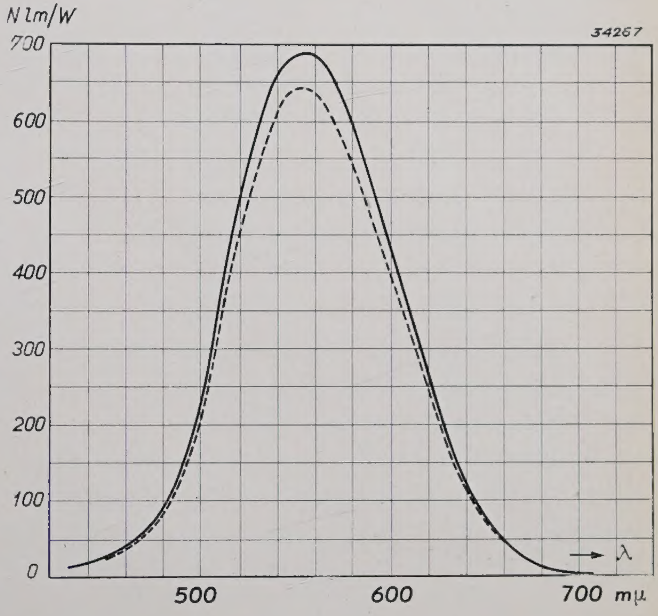

Fig. 3. Efficiency (new lumens per watt) as a function of the wave length, calculated from the data used in fig. 2. When the old constants are used a value for the maximum light yield is found which agrees well with the results of more direct determinations. The new constants, however, give a considerably higher maximum.

These uncertainties naturally do not affect the usefulness of the new candle as a photometric standard; only when energy measurements must be carried out in addition to light measurements must this be taken into account.

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[6]) A critical study of the constants c_2 and T_p is given by W. de Groot, Ned. T. Natuurk. 7, 35, 1940.

THE LARYNGOPHONE

by J. de BOER and K. de BOER.

621.395.61

In telephoning it is possible to use as excitation agent the mechanical vibrations of the speaker's throat instead of the air vibrations which occur in front of the mouth of the speaker. This method makes it possible to use the telephone in places where there is so much noise that the human voice is drowned. The picking up of the throat vibrations is done with a laryngophone, the principle and several structural details of which are described in this article. Two different types have been developed: a crystal microphone in which the chief aim has been the best possible quality of reproduction, and a carbon microphone whose sensitivity can be made so great that it can be used directly in a telephone apparatus instead of the usual microphone. A consideration of the sensitivity of the laryngophone for air vibrations as well as a series of intelligibility tests show to what degree the desired purpose has been realized in the laryngophones described.

In the electrical transmission of sound as in the telephone the first step consists of converting the sound vibrations into voltage alternations by means of a microphone. In general the action of the latter is on the following principle: a body is introduced into the sound field. This body follows the vibrations of the air, and by its movement causes for instance a resistance, a capacity or a magnetic flux to vary. From these variations, by suitable electrical connections, a voltage variation is obtained.

Since the microphone cannot distinguish between the desired air vibrations and any other vibrations which may be present, in order to attain sufficient intelligibility it is necessary that there shall not be too much disturbing sound in the chamber where the microphone is used. What, however, is the situation when the telephone must be used in a place where the disturbance level is so high that one can scarcely make oneself understandable to ones neighbour even by shouting? Consider for example the cabin of an aeroplane, a boiler factory, a ship-building yard, a mine shaft — places where it is often necessary to conduct a telephone conversation, or at least to give orders by telephone, in the midst of deafening noise.

In such places telephoning can be made possible if the speech vibrations are picked up, not out of the noise-filled air but on the throat of the speaker. The "laryngophone" by means of which this is accomplished, could in fact better be compared with an electrical gramophone pick-up than with one of the ordinary types of microphone, since the transmission takes place in this case not by way of air vibrations, but by way of mechanical vibrations, of the throat. And just as we are accustomed to being able to converse calmly in a room while a gramophone record is being played without the gramophone pick-up reacting to the speech vibrations in the air, so we may also expect that a laryngophone will be able to reproduce the vibrations of the larynx without appreciable disturbance from possible noise in the surrounding air.

A laryngophone can of course only be used instead of an air microphone if the throat vibrations have the same form as the air vibrations which occur during speech. To what degree is this true? In order to obtain some insight into this matter we shall first devote our attention to a brief consideration of the mechanism of the excitation of sound in speech.

Mechanism of the excitation of sound in speech

The air which is compressed in the lungs flows along the vocal chords through the pharynx and the mouth or nose to the outside. In pronouncing certain sounds the energy of flow of the air is converted into vibration energy at certain points where the air flux experiences a constriction. This may take place for example in the slit between the vocal chords, in the space between tongue and uvula, between the teeth, between the lips. The vibrations occurring are generally relaxation vibrations caused by the growth and dispersion of tiny air whirls, and they therefore comprise a large number of harmonics. If such an air flux, modulated by such a relaxation vibration, enters the mouth cavity, the latter acts as a resonator, and certain frequencies of the original vibration are reinforced. In this way sounds are formed which are then radiated through the mouth opening as audible sound. The vibrations of the air in the mouth are, however, also communicated to the surrounding fleshy and bony parts of face and neck and can be felt plainly on the outside as vibrations. The most suitable spot for picking up these vibrations is the throat, since here the damping layer between the cavity and the outer skin is thinnest (*fig. 1*); this is the origin of the laryngophone.

From the above it is clear that only those sounds will be manifested in the face and throat vibrations which are formed by the resonating cavities, or for which these cavities act as resonators to a considerable degree. The farther forward in the mouth the primary relaxation vibration is excited, the less this will be the case. The "explosive" consonants p, t, k and the s sounds, s, f, sh, are therefore poorly represented in the throat vibrations. Most of the other consonants, however, and all the vowels, which are practically the conveyers of speech, are formed chiefly with the collaboration of the resonating cavities. It may therefore be expected that the throat vibrations will be able to form a very acceptable substitute for the actual speech vibrations. This expectation is fully met in the intelligibility tests which we shall describe later.

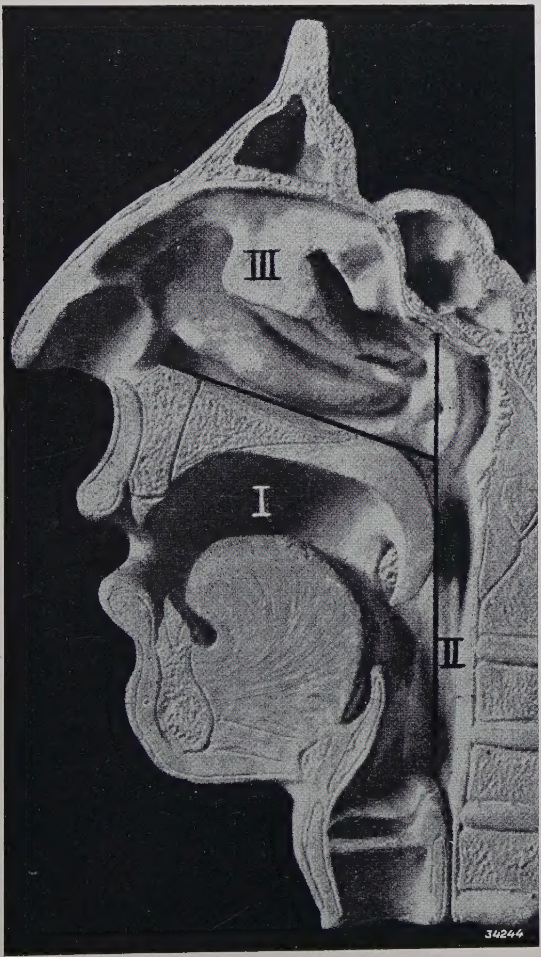

Fig. 1. Cross section of a model showing the wind pipe and the mouth, throat and nose cavities *I*, *II* and *III*. (From Panconcelli-Calzia, Einführung in die angewandte Phonetik, Fischers mediz. Buchh. Berlin 1914).

Frequency characteristic of the radiating body

When the vibrations in the oral cavity are radiated through the mouth as sound, their frequency spectrum ("timbre") experiences a certain additional alteration: the relatively small opening of the mouth radiates high frequencies better than low ones [1]). On the other hand the vibrations in the oral cavity also experience a change in "timbre" in their transmission *via* flesh and bone to the skin of the throat, due to a certain dependence of the damping on the frequency. These two facts can be given common expression by saying that the vibrations of the throat — which we here consider as the primary phenomenon for convenience' sake — must pass another organ having a certain "frequency characteristic" before they are radiated. For this statement to be valid it is necessary that all the sounds be affected according to approximately the same characteristic, which is actually found to be true. In order to make the voltage alternations resemble as much as possible the speech vibrations observed by the ear, in the case where the vibrations of the throat are picked up by the laryngophone, an element must be included in the circuit which has a frequency characteristic similar to that of the "radiator", or provision must be made that the laryngophone itself possesses a sensitivity curve which guarantees the required change in timbre.

What is the appearance of the above-mentioned frequency characteristic? In other words, what is the ratio between the velocity of the air particles and the velocity of the throat for each frequency? In order to discover this a number of speech sounds (vowels and consonants) were recorded at the same time with a calibrated band microphone and with a provisional, likewise calibrated laryngophone on two different gramophone records. For each record the average distribution of the intensity over the different frequencies was measured [2]). With the help of the calibration curves of the two microphones the velocities of the band microphone and of the laryngophone respectively were measured at every frequency. The ratio of the velocities of the air and of the throat, respectively, found in this way, is plotted in *fig. 2* as a function of the frequency (on a logarithmic scale), for three different speakers. By approximation the average characteristic obtained in the frequency range from 200 to 3 000 cycles per sec can be represented by a straight line of slope 2, which means that the "amplification factor" of the hypothetical organ which converts the throat vibrations into air vibrations is proportional to the square of the frequency.

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[1]) By approximation we may consider the radiating mouth as a pulsating sphere. For the behaviour of such a radiator *cf.*: A. Th. van Urk and R. Vermeulen, The radiation of sound, Philips techn. Rev. 4, 213, 1939.

[2]) As is usual in speech measurements these intensity distributions are recorded with a series of filters each of which passes a frequency band, half an octave broad.

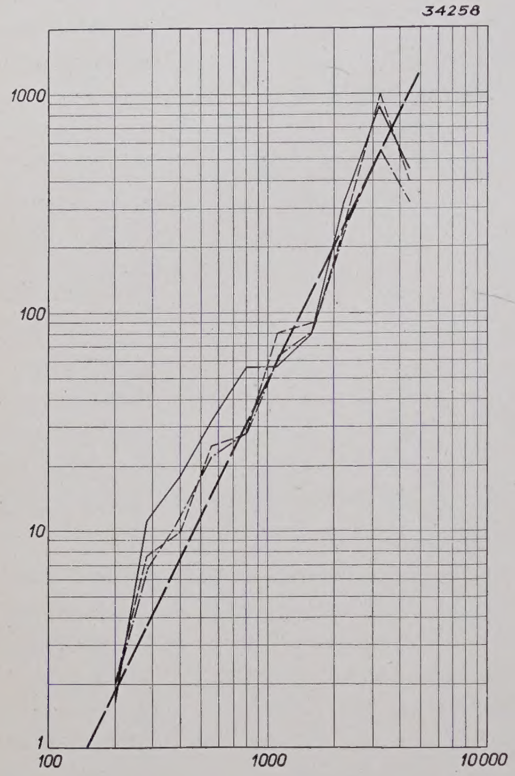

Fig. 2. Frequency characteristic of the "radiator". The average ratio between the velocity of the vibrating air particles in front of the mouth and the velocity of the vibrating throat is recorded as a function of the frequency (in c/sec) upon the pronunciation of different sounds by three different speakers. The characteristic can be represented approximately by a straight line of slope 2.

In order to obtain a voltage amplitude proportional to the velocity of the air particles, therefore, at a constant velocity of the throat the output voltage of the laryngophone plus amplifier must increase with the square of the frequency. If the laryngophone gives a voltage proportional to the velocity of the throat, then an amplifier must be used with a frequency characteristic which increases quadratically. If the output voltage of the laryngophone is not proportional to the velocity, but to the displacement of the throat, then the sensitivity of the amplifier must increase with ω^3.

For ease in replacement of separate links in the transmission it is easier when all the amplifiers occurring can have the usual flat characteristic. One will therefore attempt to construct a laryngophone which already possesses the desired characteristic and which can therefore immediately be combined with normal amplifiers. This is *a fortiori* true when a laryngophone is to be used entirely without amplifier [3]).

Excitation of the laryngophone

It has actually been found possible to construct a laryngophone with a quadratic characteristic, and the construction is even found to be quite simple.

In the case of ordinary air microphones and also in that of the gramophone pick-up the vibrating element (a membrane for instance) is set in motion directly by the vibration to be registered, while the holder in which the element is elastically suspended or clamped remains practically at rest (*fig. 3a*). In a laryngophone on this principle the amplitude of the relative velocity between membrane and holder is identical with the amplitude of the velocity of the throat, *i.e.* instead of the desired quadratic characteristic we obtain a flat characteristic. The laryngophone can also, however, be excited indirectly, namely by allowing the holder to follow the throat vibrations and leaving the vibrating element entirely free. This is represented schematically in fig. 3*b*. If the holder H (the throat) moves according to $a\,e^{j\omega t}$, then the following differential equation is valid for the relative displacement x between the holder H and the vibrating element M:

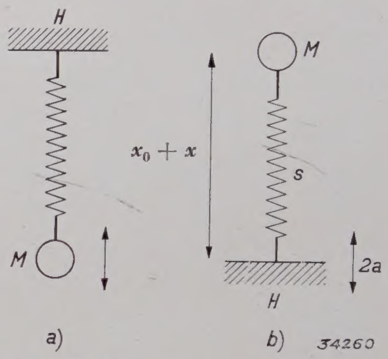

Fig. 3. a) Diagram showing the principle of a directly excited microphone. The holder H remains at rest, the exciting forces act directly on the vibrating element M.
b) Diagram of an indirectly excited microphone. A certain motion is communicated to the holder H and the vibrating element takes on a certain alternating deviation x with respect to the holder; x_0 is the distance between M and H when at rest.

$$m \frac{\mathrm{d}^2\,(x + a\,e^{j\omega t})}{\mathrm{d}t^2} + sx = 0, \quad . \quad . \quad (1)$$

where m is the mass of the vibrating element and s the stiffness of the elastic suspension. The damping has been neglected. Equation (1) can be written in the form:

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[3]) A decrease of the sensitivity at low frequencies is moreover also accompanied by the advantage that, at a constant velocity amplitude, the deviations at low tones do not become very large, which might otherwise lead to non-linear distortion.

$$m\,\frac{\mathrm{d}^2x}{\mathrm{d}t^2} + sx = ma\omega^2\,e^{j\omega t}$$

and its solution is:

$$x = A\,e^{j\omega t},$$

with
$$A = \frac{a}{\left(\frac{\omega_0}{\omega}\right)^2 - 1}\,, \quad \ldots\ldots \quad (2)$$

where $\omega_0 = \sqrt{s/m}$, the resonance frequency of the system. If the throat moves with the same velocity amplitude $a\omega$ at all frequencies, the relative velocity amplitude $A\omega$ of the laryngophone varies according to

$$\left|\frac{1}{\left(\frac{\omega_0}{\omega}\right)^2 - 1}\right|\,, \quad \ldots\ldots\ldots \quad (3)$$

which is drawn in *fig. 4.*

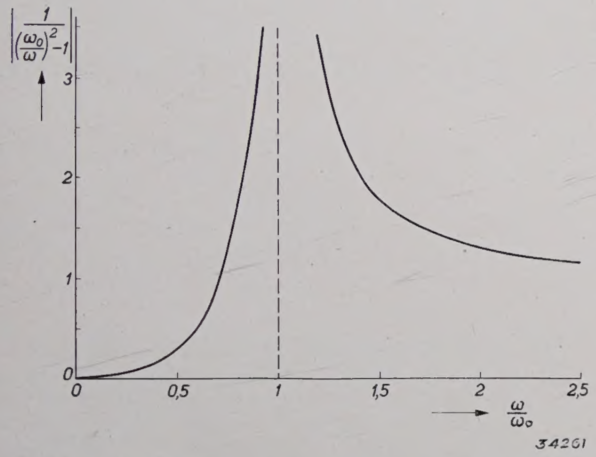

Fig. 4. Variation of the factor (3) as a function of ω/ω_0.

This frequency characteristic has the desired quadratic character in the region $\omega \ll \omega_0$, since (3) can here, by approximation, be replaced by

$$(\omega/\omega_0)^2. \quad \ldots\ldots\ldots \quad (4)$$

Practical construction

From the above it is clear that an indirect excitation of the vibrating element is indicated for the laringophone, when its resonance frequency ω_0 lies higher than the frequency region to be reproduced. On the other hand, however, the resonance frequency may not be given any arbitrarily high value since according to (4) the sensitivity of the microphone is inversely proportional to ω_0^2. For the reproduction of speech the frequencies between 500 and 2 000 c/sec are the most important ones; a suitable value for the resonance frequency therefore is in the neighbourhood of 2 000 c/sec.

Two different systems have been chosen for the actual construction: a crystal microphone in which particular attention has been paid to the quality of the reproduction, and a carbon microphone in which the main effort has been to attain the greatest possible sensitivity. We shall describe several details of the construction of these two systems.

Crystal laryngophone

The action of a crystal microphone is based on the piëzo-electric effect: certain kinds of crystals, such as Rochelle salt, assume an electric charge when they are deformed. When a plate cut from such a material at a certain angle to the crystal axes is stretched it becomes positive on one side and negative on the other; under pressure the charges are reversed. If two plates are stuck together in a suitable manner, a plate is obtained which, not by stretching, but by bending, exhibits a certain electrical tension between the upper and the lower sides. In the Philips crystal laryngophone such a plate is clamped in a holder at one end as shown in *fig.* 5. On the upper and lower sides of the plate electrodes making good contact are fastened. The voltage alternations occurring when the plate is in vibration are taken up by these electrodes.

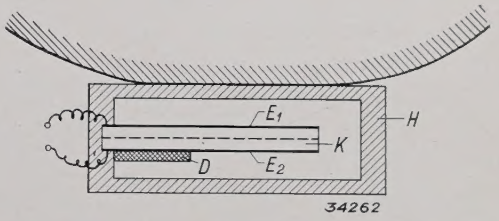

Fig. 5. Construction of the crystal laryngophone. *H* holder, one side of which is pressed against the throat of the speaker; *K* crystal composed of two discs; E_1, E_2 electrodes; *D* damping material.

The simple diagram of fig. 3*b* does not actually apply in the case of this vibrating system, since here the stiffness and the mass are distributed uniformly through the system. Nevertheless a closer consideration leads to the same result, namely that with a vibration of the holder with the frequency ω and the velocity amplitude $a\omega = b$, the plate moves with a relative velocity amplitude $\sim b\omega^2$ (as long as ω lies below the resonance frequency). If the output voltage of the crystal microphone were proportional to the velocity of the crystal the problem would be solved. The piëzo-voltage is, however, proportional to the displacement of the plate, so that at constant velocity amplitude *b* of the throat against which the holder of the microphone is pressed we obtain a microphone voltage of only $\sim b\omega$ instead of $\sim b\omega^2$.

The required correction of the microphone characteristic is obtained by connecting a relatively low resistance R in parallel with the crystal (*fig. 6*).

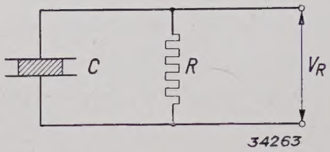

Fig. 6. Connections of the crystal laryngophone. The crystal may be considered as a condenser C upon which an alternating piëzo-voltage V acts during vibration. Resistance in parallel R, output voltage V_R.

If C is the capacity of the crystal, V the amplitude of the piëzo-voltage, then the output voltage obtained is

$$V_R = \frac{RV}{\sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}} \quad \cdot \cdot \cdot \cdot \cdot \quad (5)$$

When the resistance R is chosen so that

$$R\omega C \ll 1, \quad \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (6)$$

then

$$V_R \approx R\,\omega\,C \cdot V \sim b\omega^2 \quad . \; . \quad (7)$$

and this is the desired relation. The improvement of the characteristic is obtained at the expense of the sensitivity; condition (6) means that according to equation (7) $V_R \ll V$.

With the crystals used, capacity $C = 1000$ μμF; with a resistance $R = 10^5$ ohms in parallel, therefore the characteristic has the desired shape up to frequencies of about 1 600 c/sec, where $R\omega C$ becomes equal to unity. The slackening of the rise in the characteristic in this region is compensated partially by the fact that the crystals come into resonance at about 1 700 c/sec [4]). The resonance peak is reduced to the desired proportions by the introduction of a strip of damping material on one side of the crystal (fig. 5).

Fig. 7 shows the frequency characteristic obtained. The ideal curve is shown by the broken line; this is seen to be fairly well approached with a resistance of 10^5 ohms in parallel, in the frequency region between 100 and 3 000 c/sec. The (mean square of the) voltage which is obtained in this case amounts to 20 mV when the speech is of normal intensity.

By the indirect method of excitation, in which no moving parts need to project outside the holder, an unusually compact and sturdy construction is made possible. Moreover, the microphone is small and light in weight. *Fig. 8* shows two microphones, while *fig. 9* shows the manner in which such a microphone can be fastened into an aviator's helmet.

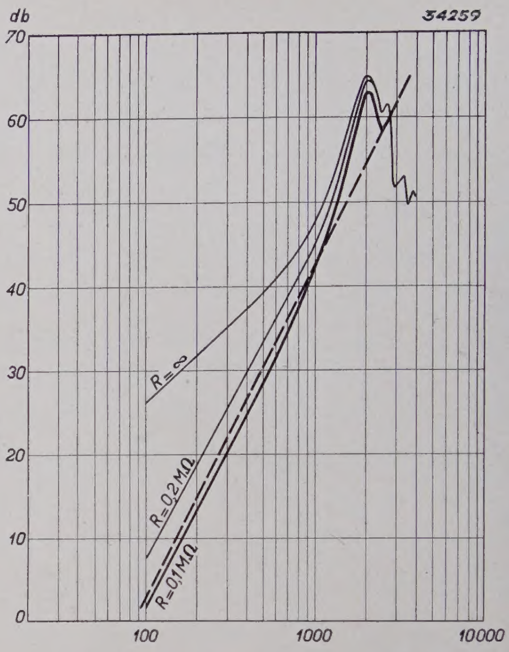

Fig. 7. Frequency characteristic obtained from the crystal laryngophone with different resistances R is parallel. With $R = 10^5$ ohms the ideal relation (broken line) is fairly well approached in the frequency region of greatest importance for speech.

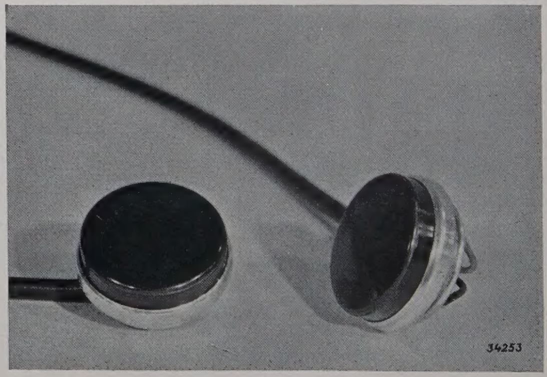

Fig. 8. Two laryngophones. Crystal type and carbon type cannot be distinguished by their appearance.

Carbon microphone

The construction of the carbon microphone is shown diagrammatically in *fig. 10*. Use is again made of the principle of indirect excitation. The vibrating system in this case is a circular membrane M which is stretched across the inside of the microphone holder. Between the membrane and the metal plate P there is a layer of granulated carbon. The electrical resistance of this layer depends closely upon the pressure at which the grains of

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[4]) It is unnecessary to take into account the resonance frequencies of higher order which occur with a vibrating continuum, since in this case they lie above 10 000 c/sec.

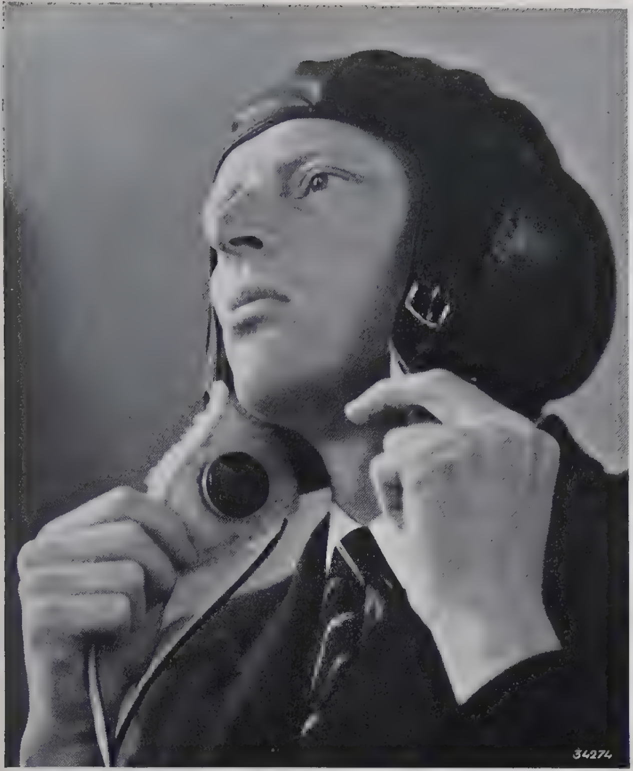

Fig. 9. The laryngophone can easily be fitted into an aviator's helmet.

carbon are pressed together. Upon vibration of the membrane with respect to the holder the carbon is compressed to different degrees, and the resulting resistance variations lead to variations in an electric current sent through the carbon. The variations are, as in the case of the piëzo- crystal, proportional to the amplitude of the membrane, so that here again the frequency characteristic (at constant velocity amplitude of the excitation) increases with ω instead of with ω^2 as desired. The too great intensity of the low tones which is hereby caused can here also be corrected if necessary in a simple manner. We shall not discuss this point here, but we shall discuss on the other hand the dimensions of the microphone in some detail since they are very important in connection with the desire to attain the greatest possible sensitivity.

The following points must be considered:

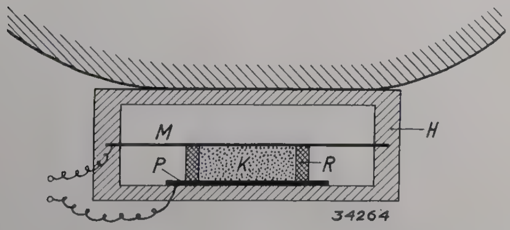

Fig. 10. Cross section of the carbon laryngophone. M membrane; P metal plate; K carbon in the space surrounded by the ring R of flexible insulating material.

1) The thinner the layer of carbon the greater the relative variations of the thickness of the layer, and thus of the resistance for the same amplitude of the membrane. If the layer is too thin, however, the non-linear distortion may become too great. Further consideration shows that maximum amplitudes of the membrane of about 0.003 mm may be expected. With this in view a thickness of the carbon layer of about 1 mm has been chosen, and with this no appreciable non-linearity was observed.
2) The bending of the membrane is greatest at the center and zero at the edges. The change in resistance is determined by an effective value of the bending, an average over the whole surface. It is therefore desirable to allow only the centre of the membrane to press upon the carbon (see fig. 10) and thus to make the membrane relatively very large. A limit is set to its size by the requirement that the mass of the membrane must be small enough to give the necessary high value of the resonance frequency. The diameter of the carbon layer may also not be decreased at will. The requirement that the laryngophone must be able to be connected in the place of the ordinary microphone in standard telephone connections had to be taken into account, and this meant that the average resistance of the carbon layer had to have a prescribed value (about 75 - 100 ohms here).
3) The size of grain of the carbon was also influenced by the latter consideration. Since the sensitivity increases with the size of grain it would seem preferable to choose a coarse grain. However, the resistance also depends upon the grain size, so that in connection with the chosen thickness and diameter of the carbon layer the choice of grain size is limited.

The sensitivity obtained is about 200 times as great as that of the above-described crystal laryngophone at a frequency of 1 000 c/sec (the resonance lies at about 2 000 c/sec). Measured during speech, at normal speech intensity and in normal connections (see *fig. 11*) an average power 0.2 mW is obtained.

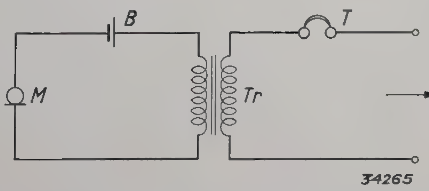

Fig. 11. Normal connections when the carbon microphone is used. M microphone, B battery of 4 volts, Tr transformer 1 : 2, T telephone, L telephone line.

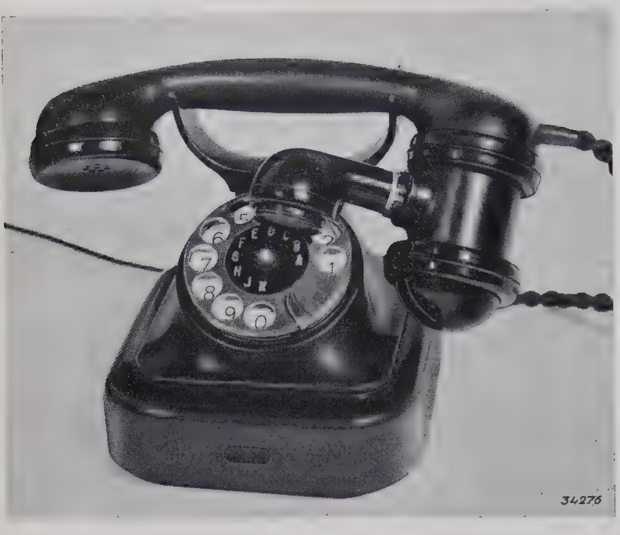

Fig. 12. By means of a rotating intermediate section a laryngophone can be attached to the ordinary combination of receiver and microphone of a telephone apparatus.

Fig. 12 shows how the laryngophone can be added to the usual combination of receiver and microphone of a telephone apparatus by means of a removable and adjustable intermediate section. When the arm with the laryngophone is turned to such a position that the laryngophone rests against the throat when the apparatus is held in the usual way (*fig. 13*), the air microphone of the apparatus is automatically disconnected, so that the disturbing air vibrations are no longer transmitted.

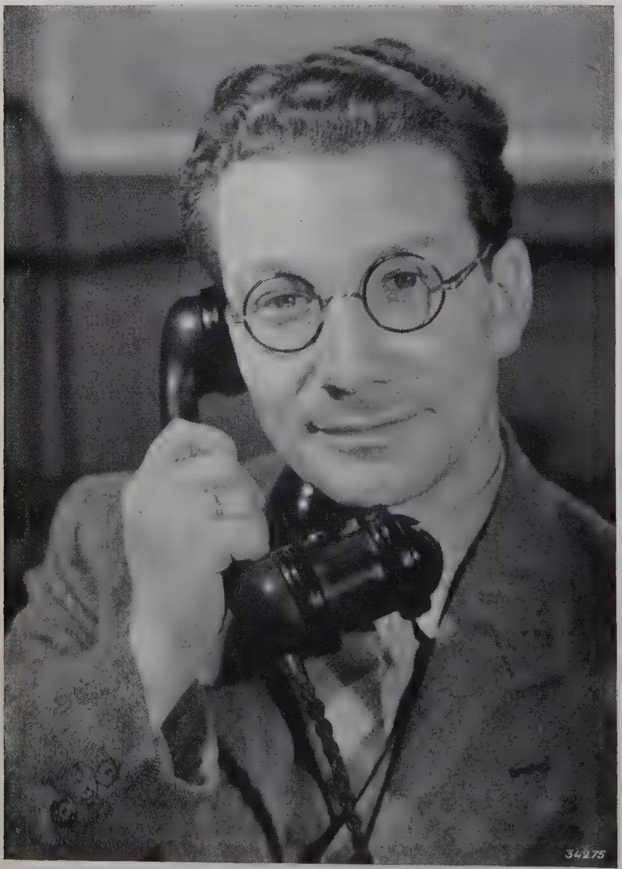

Fig. 13. When the arms to which the laryngophone is attached are turned into such a position that the laryngophone rests against the throat when the apparatus is held in the ordinary way, the air microphone is automatically disconnected by a switch situated in the intermediate section.

The effect of noise

How does the laryngophone react towards air vibrations? To use a simplified image, we may consider the microphone holder to be a flat plate with the area O and the mass m, which is fastened to a very weak spring (the throat), and upon one side of which the sound pressure p acts. For the displacement y of the plate the following equation is roughly valid:

$$m \frac{d^2y}{dt^2} = p\, O.$$

When p varies with the frequency ω, the plate moves with the same frequency, and an amplitude

$$a = \frac{p\, O}{m} \cdot \frac{1}{\omega^2} \cdot \quad \ldots \ldots \quad (8)$$

Since in the ideal case (a crystal microphone with as mall resistance in parallel) the laryngophone gives an output voltage which is proportional to ω^3 when the amplitude of the holder is constant, the sensitivity of the laryngophone for air vibrations increases proportional to ω. At low frequencies therefore it is least sensitive to air vibrations, which is fortunate, since in many cases the disturbing sounds in question (the noise of motors for example) have their greatest intensity at lower frequencies than speech.

The influence of air vibrations can be calculated with the above-described simple model. In the cabin of an aeroplane there is an average disturbance level of 114 phons. By definition we hear a noise of 74 phons as loud as a tone of 1 000 c/sec with a sound pressure of 1 dyne/cm². We may therefore substitute for the noise in an aeroplane a tone of 1 000 c/sec with a sound pressure of:

$$10^{\frac{1}{20}(114-74)} \cdot 1 = 100 \text{ dyne/cm}^2.$$

With an area $O = 10$ cm² and a mass $m = 18$ g of the laryngophone, the latter, according to (8), has an amplitude

$$a = \frac{100 \cdot 10}{18 \cdot (2\pi \cdot 1000)^2} = 1.41 \cdot 10^{-6} \text{ cm}.$$

From the calibration of the laryngophone it is found that at this amplitude (with a low resistance in parallel) a voltage of about 4 mV is obtained. Actually the interference observed by the listener will be less than would be represented by 4 mV, since, as stated above, the low frequencies in which the noise is concentrated are transmitted in less intensity than the frequency of 1 000 c/sec taken as a basis, due to the nature of the frequency characteristic of the laryngophone. If we now take into account that this same crystal microphone gives an output voltage of 20 mV in normal speech, and that, even when the intensity of speech and disturbing noise is the same, the intelligibility is satisfactory [5]), it is clear that when a laryngophone is used the noise surrounding the speaker is practically absent for the listener. The only effect of the noise is that the speaker, not hearing his own voice, begins to articulate less clearly or in an unnatural manner.

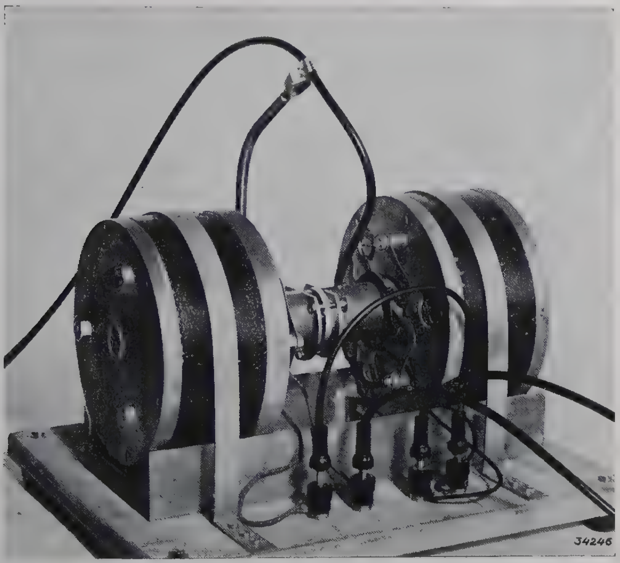

Fig. 14. Apparatus with which the calibration of an indirectly excited laryngophone may be calibrated. Two loud speaker systems are activated by two identical alternating currents differing in phase by 180°, while the laryngophone to be tested is clamped between the two coils.

It will perhaps interest the reader to know how the repeatedly mentioned calibration of the laryngophone is carried out. The apparatus shown in *fig. 14* is used for this purpose. Two loud speaker systems without cones are set up facing each other so that they can be slid back and forth. A brass plate is fastened to the coil of each system. The laryngophone is clamped between these two plates, and alternating currents of equal frequency and amplitude but with 180° difference in phase are sent through the coils, so that the laryngophone is moved back and forth as a whole. The output voltage produced, given by the laryngophone when excited in this way, is measured with the help of an amplifier and a thermocouple, while at the same time the deviations of the laryngophone are determined by setting the needle of a calibrated gramophone pick-up on it and measuring the output voltage of the pick-up.

Intelligibility tests

The utility of the laryngophone can be tested directly by quantitative determinations of the intelligibility. Both types of laryngophone have been examined in this respect in the following way. A number of listeners were placed in a quiet room where they could hear the speech from a loud speaker (in the case of the crystal microphone) or with head phones (in the case of the carbon microphone). At the spot where the speakers (three in our case) were situated the normal noise level of an office prevailed, or a disturbance level of 123 phons could be created. The speakers then read 50 unconnected words in the native language (Netherlands) of the listeners.

In the test on the crystal microphone, which was provided with only a small resistance (10^5 ohms) in parallel for the sake of obtaining the best possible reproduction, an intelligibility of 86 per cent was found without extra disturbing noise. Since normal telephone apparatus give no greater intelligibility than about 90 per cent, the quality of reproduction of the crystal laryngophone may be considered quite satisfactory. When the speakers were surrounded by the above-mentioned noise of 123 phons, the intelligibility decreased by only a few per cent; it then became 80 per cent. The decrease in this case could be ascribed almost exclusively to the less clear articulation of the speakers. For the sake of comparison it may be mentioned that the intelligibility with an ordinary telephone apparatus diminishes to zero when the speaker is surrounded by a noise of only 90 phons!

As was to be expected, the carbon laryngophon gave somewhat lower intelligibility than the crystal microphone. The value without disturbing noise was 77 per cent. After adding the noise of 123 phons the intelligibility decreased to 68 per cent. This is still high enough to enable one to follow a conversation, and thus certainly high enough to be able to make understandable orders, or similar communications of a familiar, recurring nature. If desired, the intelligibility can moreover still be considerably increased by using telephones with a better frequency characteristic than that possessed by the commonly used telephone.

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[5]) See R. Vermeulen, Auditorium acoustics and intelligibility, Philips techn. Rev. **3**, 1938, 1938.

The most important possibilities of application for the laryngophone have already been mentioned at the beginning. Another application would be the use of the laryngophone in combination with gas masks. An air microphone is quite useless in this case due to the resonances in the small sealed air space inside the mask. When a laryngophone is used this difficulty is met, with the added advantage that the microphone can be passed from one speaker to another without it being necessary to open the mask.

DRILLING DIAMOND DIES

In the Philips factory for drilling diamonds, which may be considered one of the largest of its kind in the world, dies for drawing wire are made with diameters from 10 microns up. Part of the production is destined for use in the other departments, namely for drawing wire of tungsten, molybdenum and various other metals.

The diamonds which are made into dies, are first cut off flat on the two opposite sides of the future bore. Facets are then ground in two mutually perpendicular planes parallel to the direction of the bore (see *fig. 1*), which make it possible to follow the drilling process and continually to control it by means of a microscope (title photograph). The diamond so prepared is fastened into a holder. The drilling is done with a needle of a special shape

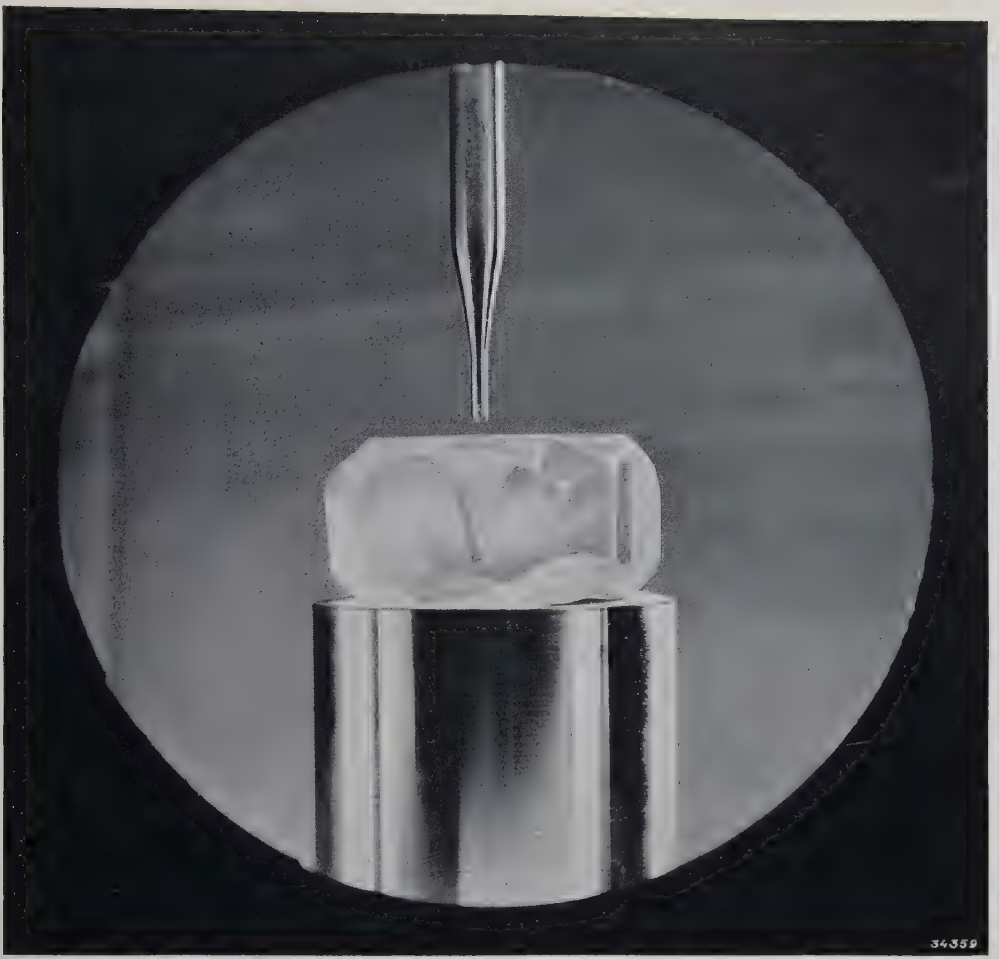

Fig. 1

(fig. 1) which is allowed to take up diamond dust mixed with oil in the pores of its surface. The bore must be given a very definite shape and polish for each material to be drawn in order that the die may have a long life. On the side where the wire leaves the die the drawing channel opens out into a wider depression as may clearly be seen in the photomicrograph *fig. 2* (magnified 120 times).

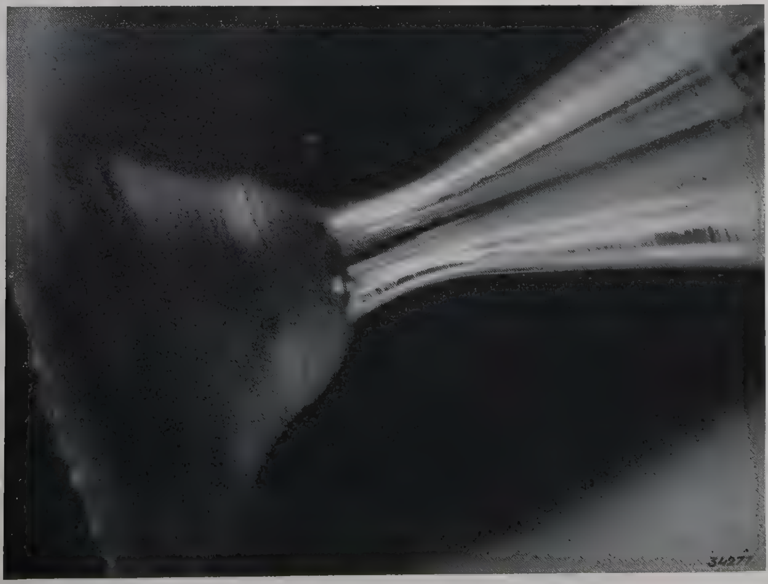

Fig. 2.

REFLECTING SURFACES IN THE NEIGHBOURHOOD OF LINEAR SOURCES OF LIGHT

by N. A. HALBERTSMA.

628.936

Because of the low surface brightness of tubular sources of light it is not necessary to take precautions against glare by means of fixtures. It may, however, be advisable to introduce in the neighbourhood of such light sources specularly or diffusely reflecting surfaces of such shape that they prevent the loss of part of the emitted light for the desired illumination purpose.

In illumination by means of point sources of light, or at least with sources of light of sufficiently small dimensions use is nearly always made of reflectors. This is for two reasons:

1) To decrease the maximum brightness seen by the eye of the observer, thus preventing glare,
2) By means of suitable reflectors to employ the total light flux more efficiently for the illumination of given surfaces than would be the case without such reflectors.

When tubular sources of light are used, the first reasons for using reflectors is no longer valid, since in this case the brightness is generally low enough lower so that there is no risk of glare. While for example with an electric lamp of 150 dlm with a clear glass bulb the brightness of the incandescent coil is 500 c.p./cm^2, and with an inside frosted lamp it is still 3 c.p./cm^2 on an average, and reaches a maximum of 15 to 20 c.p./cm^2, it falls to about 0.3 c.p./cm^2 when the filament is mounted in an opal glass tube, like the „Philinea" lamp. For a mercury-discharge lamp [1]) where the discharge takes place in a glass tube covered on the inside with a layer of luminescent material the brightness is also about 0.3 c.p./cm^2.

When these brightness values are considered, it is obvious that "Philinea" lamps as well as the luminescent discharge lamps can be used entirely without reflectors as far as the danger of glare is concerned, if only the background is light coloured and is sufficiently illuminated. The second reason for the use of reflectors, namely the more efficient use for the desired purpose of the light flux produced retains, however, its full force even in the case of linear sources of light.

The question now is whether it is possible to render the distribution of the light emitted over the different directions in space much more satisfactory by at introducing reflecting surfaces in a suitable way into the neighbourhood of a linear source of light. In the lengthwise direction of the source these surfaces must be at least as long as the source itself. Since in general it is desirable to avoid giving the combination of reflecting surfaces a clumsy and heavy appearance, the dimension of the reflector perpendicular to the axis of the slender light source should be kept small, and it should be mounted close to the source of light. This consideration leads to the use of cylindrical mirrors which need not be less decorative than the light source itself. With such mirrors curved around the tubular light source in one direction only it is of course never possible to obtain such a concentration of the light as can be obtained with a point source by means of surfaces of revolution such as paraboloids.

If the reflecting surfaces are actually very close to the tubular source there is a danger that a large part of the reflected light will again strike the surface of the tube, so that only after several reflections, in which part of it is absorbed, will the light succeed in leaving the space between source and reflector and contribute to the desired illumination. It is therefore important to study the best possible construction of the reflecting surfaces keeping this danger in mind.

In the first place we shall consider the effect of specularly reflecting surfaces on the distribution of the light flux. We shall then consider the influence of diffusely reflecting surfaces.

The action of specularly reflecting surfaces

We shall begin our discussion with a study of the reflection of the light from a tubular source by a plane mirror parallel to the source. *Fig. 1* shows a cross section of this arrangement perpendicular to the axis of the tube. The centre M_2 of the circular cross section of the source lies at a distance $d/2$ from the plane mirror AB. At a distance $d/2$ beyond the mirror lies the mirror image of the actual source of light, and this is again a luminous tube, whose centre lies at M_1. The rays reflected by the mirror AB all seem to come from the cylindrical surface of the mirror image of the original light source. If we neglect the loss of light upon reflection the problem is reduced to that of the light distribution of two similar parallel cylinders whose surfaces radiate diffusely, *i.e.* in such a way that the brightness is the same in all directions. This is called radiation according to Lambert's law.

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[1]) Philips techn. Rev. 4, 353, 1939.

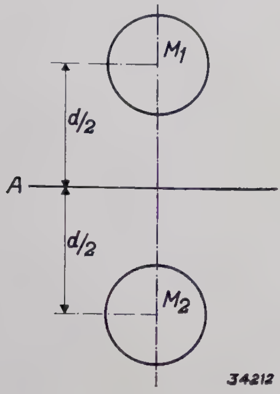

Fig. 1. Cross section of a tubular source of light, centre M_2 and of its mirror image, centre M_1, with respect to the plane AB.

The cross section of the two luminous tubes of diameter $2\ r$ and with a distance d between their axes is shown in *fig. 2*. The light intensity I_α at any given angle α in the plane perpendicular to the axes of the two tubes at their middle point, when the radiation is entirely diffuse, is proportional to the apparent size of the total luminous surface observed at an angle α. The light intensity in our case is therefore equal to the sum of the light intensity of the first cylinder [2] $C \cdot 2\ r$ and that of that part of the second cylinder which is not screened by the first one. This latter contribution to the total light intensity is variable and amounts to: $C\ (r + y) = C \cdot d \sin \alpha$. The total luminous intensity is therefore:

$$I_\alpha = C\ (2r + d \sin \alpha) \quad . \ . \ . \ . \quad (1)$$

For $\alpha = 0°$ one cylinder entirely screens the other, and the light intensity becomes:

$$I_0 = C \cdot 2r, \quad . \ . \ . \ . \ . \ . \quad (2)$$

which is supplied by one cylinder alone, and represents the minimum light intensity for this pair of tubes. At angles equal to or greater than the limiting angle α_1, where:

$$\sin \alpha_1 = 2\ r/d, \quad . \ . \ . \ . \ . \quad (3)$$

the total light intensity assumes its highest value:

$$I_{\alpha_1} = C \cdot 4\ r, \quad . \ . \ . \ . \ . \ . \quad (4)$$

which is twice the minimum value and is indeed the sum of the equal light intensities of the two tubes.

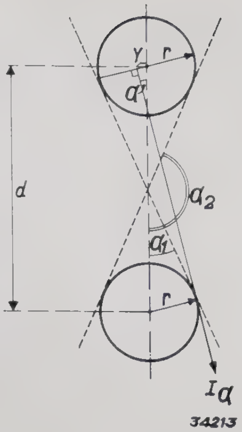

Fig. 2. Cross section of two similar, parallel tubular sources of light. I_α represents the luminous intensity occurring on the plane perpendicular to the axes of both tubes at their middle point, at any given angle α.

Fig. 3 shows how the light intensity varies for different distances between the tubes when the angle α varies from 0° to 180°. When the tubes touch one another ($d = 2\ r$) the limiting angle is reached at $\alpha_1 = 90°$ and an intensity equal to twice that of one lamp is observed only in a direction perpendicular to the plane through the axes

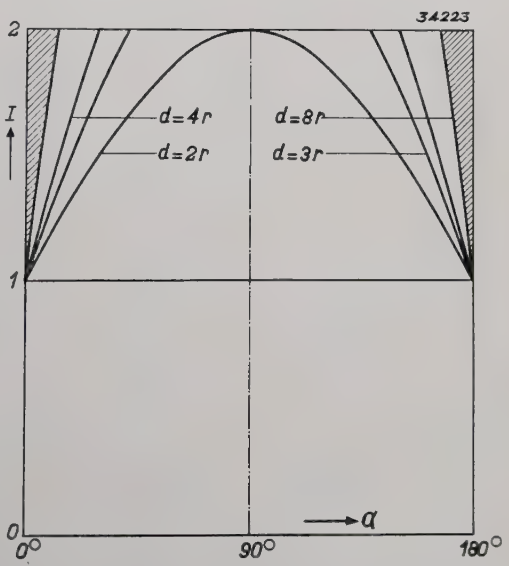

Fig 3. Under the assumption that no light is reflected by their surfaces, the variation of the combined luminous intensity of two parallel lamps at different distances is calculated as a function of the angle α in fig. 2. The results are sine curves. For 0° and 180° the luminous intensity is at a minimum, and is equal to the intensity of a single tube. At $\alpha = 90°$ the intensity reaches a maximum equal to twice the intensity of one tube.

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[2] The constant factor C in all these expressions is determined by the brightness of the surface of the cylinder and its length.

of the two lamps. When the lamps are farther apart the limiting angle α_1 becomes smaller according to formula (3), so that the doubled light intensity prevails throughout a much larger angle, namely from α_1 to $\alpha_2 = 180° - \alpha_1$. When $d = 8r$ only the shaded section of the total light flux is intercepted. It follows from fig. 3 by calculation of the areas bounded by sine curves that, at different distances between the axes of the tubes, the percentages given in the second column of *table I* of the total light flux emitted by the two lamps together are intercepted.

Table I

Percentage of light flux intercepted at different distances between two parallel luminous tubes.

	calculated; without reflection	measured; with reflection
$d = 2\,r$	17%	6,2%
$d = 3\,r$	11%	3,4%
$d = 4\,r$	8%	2,9%
$d = 8\,r$	4%	1,7%

The figures in the second column of table I would indicate the total loss of light flux only if the lamps could absorb completely all radiation falling upon them. This is of course by no means the case; the diffusing layer on the tube wall will always reflect a considerable part of the incident light. This is proved by the third column of table I and by *fig. 4* which represents measured light distribution for two similar parallel luminous tubes. It may be seen that in the horizontal direction ($\alpha = 90°$) the light intensity is actually greater than twice the intensity of one tube of the pair in question. This excess is provided by that part of the light which is able to escape from the space between the two lamps after having been diffusely reflected one or more times by the tube walls.

While the surface of a single cylinder obeying Lambert's law appears uniformly bright, two parallel luminous tubes exhibit a greater brightness on the sides facing each other than on the sides away from each other due to the reflection of each others' light. This phenomenon will be more intense the closer the tubes are brought to one another, and we therefore may conclude that *the maximum luminous intensity of the pair of tubes will be greater the closer the two tubes are brought to each other.*

If we now determine the loss of light from the measured light distribution curves of fig. 4 we find it to be about $^1/_3$ of the loss calculated when the diffuse reflections are neglected. The results are given in the last column of table I. The fact that about $^2/_3$ of the primarily intercepted light flux is saved is due to the high diffuse reflection factor of the milk glass of which the tubes used in these experiments are made. If, however, we are concerned with the luminescent discharge lamps described in an earlier number of this periodical (see footnote[1]) it is necessary to take into account the fact that the luminescent layer has a smaller coefficient of reflection than milk glass, so that the values in the third column will be larger.

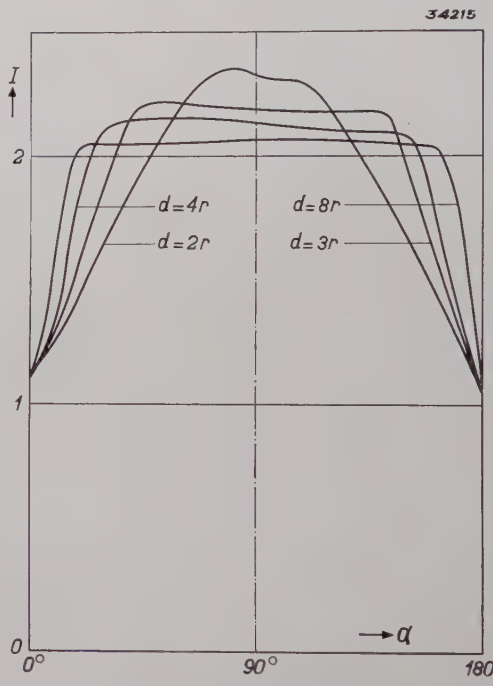

Fig. 4. Measured variation of the luminous intensity for two parallel luminous tubes. At $\alpha = 0°$ and 180° the intensity is again at a minimum and equal to that of a single tube. Perpendicular to this plane, however, the maximum intensity is found to be greater than twice that of a single tube, due to the fact that the light reflected at the surface of the tube can be emitted in a lateral direction.

The practical conclusion from the table is that in order to avoid appreciable losses of light it is advisible not to bring the linear sources of light closer together than a distance equal to their diameter ($d > 4\ r$). In agreement with this they must also not be brought closer to a specularly reflecting plane surface than a distance at least equal to their own radius. Keeping the transverse dimension of the mirrors small, they should be so placed that the reflected light cannot again strike the tube because of the absorption. If we examine what parts of a horizontal plane mirror placed above a horizontally suspended tubular lamp are most important for the reflection of the light directly downward, we find that these are only relatively narrow strips of the plane mirror (*fig.* 5). These most effective strips begin at the lines of intersection of the plane of the mirror with the vertical tangent planes of the luminous cylinder, and continue further away from the cylinder. The strip of the plane mirror lying just above the lamp is less well able to reflect light from the lamp directly downward, so that this part is actually of little practical use. It is better to place the strips of mirror somewhat to the side above the lamp.

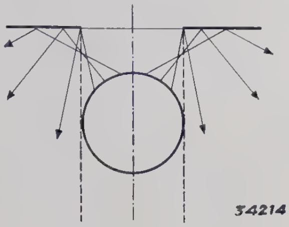

Fig. 5. Reflection of the light of a luminous tube on a plane mirror parallel to the tube. Strips of mirror which do not lie just above the mirror are able to reflect the light which is radiated upward in a downward direction again, without its striking the tube.

In a very simple way, with the aid of two plane mirrors, it is possible to cause all the light emitted upward to be reflected downward again along the sides of the lamp. The two mirrors should have a V-shaped cross section. This combination is placed directly above and parallel to the axis of the lamp (*fig.* 6). The two plane mirrors S_1 and S_2 are now placed at such an angle that they are perpendicular to the tangents l_1 and l_2 respectively in fig. 6. The surface of the mirrors in this position will not reflect any light on to the lamp. The closer the point of intersection C of the two plane mirrors is brought to the lamp, the steeper the angle at which the plane mirrors must be set and the more the upward radiation of the lamp is reflected laterally (*fig.* 7).

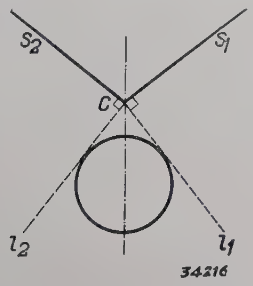

Fig. 6. Cross section of a tubular source of light with two plane mirrors arranged in V-form above it. The tangents l_1 and l_2 from C to the surface of the tube are perpendicular to S_1 and S_2 respectively.

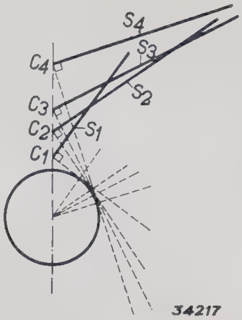

Fig. 7. Positions of plane mirrors which reflect the light downwards as much as possible without causing it to strike the surface of the tubular light source.

As a final problem relating to specular reflection we shall study the shape of a mirror which reflects downward all the light incident upon it from the tubular lamp, and yet in such a way that it does not strike the lamp again. *Fig. 8* shows the shape of the cross section of such a reflector. It may be considered as built up of infinitesimally small strips each of which is oriented as favourably as possible for its position in the manner explained above. Each of these strips is thus perpendicular to the tangent drawn from it to the circular cross section of the lamp. The final shape of the cross section of the mirror therefore becomes that of the involute of the circular cross section of the lamp.

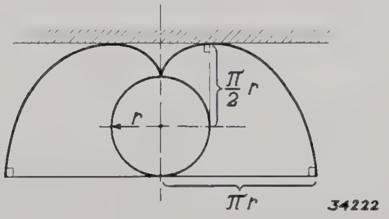

Fig. 8. Shape of a curved mirror to give the best possible downward reflection of the upward radiations of a tubular lamp. The cross section of the mirror is the involute of the circular cross section of the tube.

If we let the edge of the mirror touch the top of the lamp, the plane tangent to the mirror at that point is vertical. If we continue the mirror so far that it catches all the light reflected upwards the tangent plane of the mirror at the end point is again vertical, and the width of this reflecting cove around the linear source of light is only π times the diameter of the tube itself.

The axis of the tubular lamp lies at a distance $\pi/2$ times its own radius lower than the surface of the the ceiling. The distance from the tube wall to the ceiling, in the case of this involute cross section, is thus found to be only $(\pi/2-1)\ r = 0.507\ r$. The lamp may therefore in this case be placed only half as far away from the ceiling as was found advisable in the case of plane horizontal mirrors.

Reflection by diffusely reflecting surfaces

As stated in the introduction it is possible to employ linear sources of light without any shade or reflector because of the low brightness of the types now in use. In order to avoid exessive contrasts it is, however, advisable to take care that the ceiling, the walls or other diffusely reflecting surfaces in the neighbourhood of the linear sources are white, or at least light in colour.

In this way it is possible at the same time to obtain a great improvement in the effective illumination. The diffuse reflection of a white surface may in fact very well be compared with the specular reflection of ordinary mirrors. In the case of a glass mirror a specular reflection of 85 to 90% per cent is obtained, while the diffuse reflection of a freshly whitewashed ceiling may also amount to 85 to 90 per cent. If it is not specially necessary to concentrate the light in a certain direction, whitewashed ceilings and walls may be considered suitable reflectors.

Upon reflection by a diffusely reflecting surface in the neighbourhood of a tubular source of light it is inevitable that part of the reflected light should again strike the lamp itself. By repeated reflections between the lamp and the white surface part of the light radiated is always lost. The magnitude of this loss has been investigated in the following experiments.

Diffuse reflection by a plane surface

The intensity was measured of the illumination which is provided at a distance of 425 cm by a tubular lamp 50 cm long and 3 cm in diameter with a white plane surface of the same length and a width of 80 cm set up behind it. The measurement was carried out on planes (see *fig. 9*) which made angles of 0°, 15°, 30° and 45° with the reflecting plane surface. The distance between the surface of the tube and the reflecting surface varied from 0 to 24 cm. By subtracting each time from the results of the measurement the intensity of illumination determined without a reflecting surface, the intensities of the reflected light are found. They are indicated in *table II* and in *fig. 10* for two of these angles.

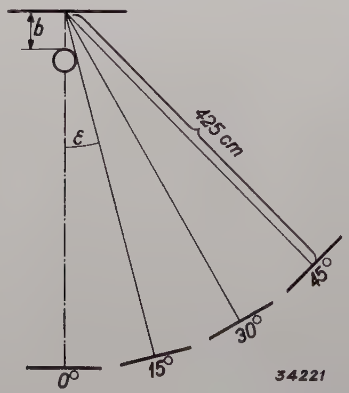

Fig. 9. Cross section of a luminous tube with a diffusely reflecting plane parallel to it and at a distance of b above it. The illumination is measured on a plane parallel to the source and at various angles ε with the diffuse reflector, and at a distance of 425 cm from it.

Table II

Intensity of illumination due to diffusely reflected light, measured in the case illustrated in fig. 9 at various angles ε and for different distances b, expressed in per cent of the intensity of direct illumination provided by the tubular lamp.

	$\varepsilon = 0°$	15°	30°	45°
$b = 0$ cm	64%	64%	63,5%	60%
1,5	70	70	68	63
3	67	67	65	59
6	63,5	63	60	53
12	53	52	48	42
18	42	41	38	32
24	34	33	31	26

As might have been expected the intensity of illumination on the measuring surface due to reflection increases when the source of light is brought closer to the reflecting surface. More light falls upon that surface so that it is able in turn to send out more light. If, however, the lamp comes closer than 6 cm, *i.e.* twice its diameter, to the white surface, the increase in the intensity of illumi-

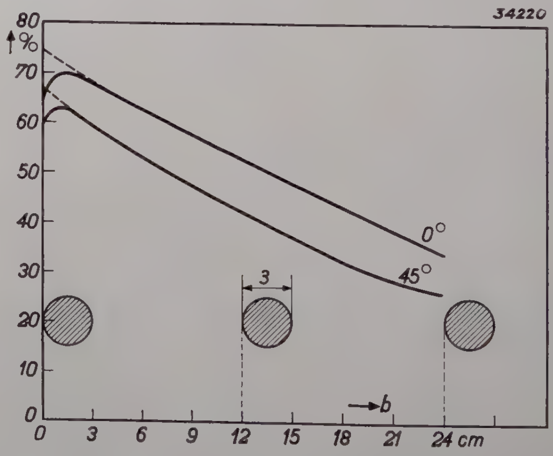

Fig. 10. Intensity of the reflected light measured in the case shown in fig. 9 in directions at angles of 0° and 45° with the normal to the diffusely reflecting plane placed at a variable distance b from the luminous tube.

nation due to reflection becomes less than was to be expected from the values at greater distances, and finally it changes to a decrease. When the surface of the tube touches the reflecting surface, *i.e.* when $b = 0$, the illumination intensity due to reflection at an angle of 0 and 45° amounts to 64 and 60 per cent respectively of the direct illumination intensity, while one might have expected the values 75 and 67 per cent, respectively, from the shape of the curves for greater distances between the lamp and the diffusely reflecting plane.

The relative decrease in the intensity of the light obtained by diffuse reflection for a tubular lamp touching the reflecting surface amounts to 15 per cent and 10 per cent at the angles 0° and 45°, respectively, according to the results of above measurements. The fact that the reflection at 45° is somewhat better than that at 0° may be ascribed to the fact that in the former case the light reflected toward the light source itself has a greater chance of escaping in a lateral direction than in the latter case, perpendicular to the reflecting surface. If we inquire, for example, what is the loss at a distance b of 1.5 cm (this is equal to the radius of the tubular lamp used) compared with the expected increase of the intensity of illumination, it is found to be only 3 per cent as with specular reflection. It is therefore obvious that care must be taken that the distance between the diffusely reflecting surface and the surface of the tube is at least equal to the radius of the tube, just as in the case of specular reflection.

Diffuse reflection by a cylindrical concave surface

As we have seen in the foregoing, a plane white surface introduced into the neighbourhood of a tubular lamp will always reflect a considerable portion of the light falling upon it back into space. If, however, curved white surfaces are used the situation may be much less favourable, because the light has more difficulty in escaping from the space between the lamp and its surrounding curved surface. As an example we shall consider the case in which the tube of diameter d is surrounded by a concentric semi-cylindrical reflector of diameter D whitened on its inner surface.

In *fig. 11* the situation is sketched for the case in which the ratio $D : d$ of the diameters is fairly large. The angle α_1 ($\sin \alpha_1/2 = d/D$), within which the diffusely reflected light is screened by the tubular lamp, is therefore small. The light which is reflected within the angle α_1 will again be partially reflected by the surface of the source and then contribute once more to the emission of the lamp. Part of the light flux which falls outside α_1 is again incident on the diffusely reflecting surface, and then finally contributes to the desired illumination.

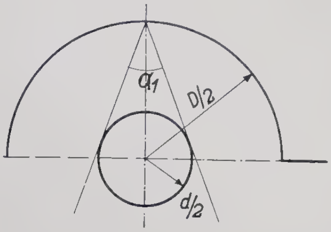

Fig. 11. Cross section of a luminous tube of diameter d surrounded by a large semi-cylinder of diameter D. The diffusely reflected light is intercepted only within a small angle α_1 by the tube.

If the ratio between D and d is only slightly greater than unity, *i.e.* if the cove is made to surround the lamp more closely, as indicated in *fig. 12*, the angle α_2 within which the reflected light is intercepted becomes much larger then α_1 in fig. 11. Only an extremely small part of the light flux from the diffusely reflecting white surface will then be able to escape directly through the narrow opening. In the limiting case in which the two diameters are equal ($D = d$), of the half of the total light flux emitted upward, only that part will not be lost for the purpose in view which returns through the glass wall to the interior of the tube.

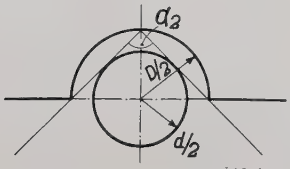

Fig. 12. Cross section of a luminous tube of diameter d closely surrounded by a semi-cylinder of diameter D. The diffusely reflected light is now intercepted by the tube within a wide angle α_2.

If the choice of the diameter of the surrounding semicylinder is determined by the brightness which one desires the whole to possess, it is necessary to know how this brightness can be calculated from the given brightness of the surface of the tube. As has already been explained in this periodical [3]), at sufficiently short distances from linear sources of light the propagation of the light may be considered to take place by way of concentric cylinders, so that the brightness is then inversely proportional to the distance from the axis of the tube. The light which, coming directly from the tubular lamp, is reflected for the first time by the diffusely reflecting concave surface, would, with a reflection coefficient of 1, give a brightness of d/D times that which the surface of the tube itself provides. Actually we may for instance be concerned with a reflection coefficient of 0.8, so that we would then calculate with 0.8 d/D times the brightness of the tube wall. Over against this however is the fact that we must not consider only the light which has been once reflected at the concave surface, but must consider numerous successive reflections between the different parts of the diffusely reflecting concave surface. If the diameter of the latter is large compared to that of the tube ($D \gg d$), then upon reflection according to Lambert's law we find that about 36 per cent of the reflected light is once more incident on the concave surface, so that the light reflected for the second time gives a contributory brightness which is $0.86 \times 0.36 = 0.29$ times the original calculated brightness. Due to the successive reflections therefore there is a geometrical series of contributions to the brightness with a ratio of 0.29, so that finally a brightness is obtained which is $0.8/(1 - 0.29) = 1.13$ times the originally calculated brightness.

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[3]) Philips techn. Rev. **4**, 181, 1939.

X RAY PHOTOGRAPHS WITH EXTREMELY SHORT EXPOSURE TIMES

by W. J. OOSTERKAMP.

621.386.8 : 778.33

When an X-ray tube is loaded for a very short time the specific focus loading may be considerably higher than normal. The amount of radiation available therefore decreases relatively slowly with the time during which loading is applied. The experiments which are described in this article show that simple objects may be photographed with an ordinary X-ray tube with exposure times of the order of one millionth of a second.

In order to take an X-ray photograph a certain amount of X-radiation is necessary, which amount depends upon the nature of the object to be photographed. The amount of X-radiation obtained is, except for a proportionality factor depending upon the tube voltage, given by the product of three quantities the area of the focus of the X-ray tube, the power supplied per unit of this area (the so-called specific focus loading W) and the time of exposure (τ).

When the object to be photographed is moving, the time of exposure may not exceed a certain limit in order to restrict the lack of sharpness due to the motion. The two other factors also have their limits: the focus may not be too large for the sake of sharpness in the image, while the specific focus loading is limited by the permissible increase in temperature (T_m) of the material of the anode.

There is thus a limit to the amount of X-radiation available. The permissible specific focus loading W_m however depends upon the time of exposure τ, according to the equation [1])

$$W_m = \frac{T_m \sqrt{\pi k c}}{2} \cdot \frac{1}{\sqrt{\tau}} \cdot \quad . \quad . \quad . \qquad (1)$$

k is here the thermal conductivity, c the specific heat of the anode material. Thus when full use is always made of the permissible focus loading the available X-ray energy (which is proportional to $W \tau$) does not decrease proportionally with τ, as might be expected in the first instance, but only with $\sqrt{\tau}$.

With the present quality of sensitive material (films and intensifying screens) large objects whose photography requires a considerable amount of radiation, such as the thorax, can be photographed with exposure times of the order of 1/100 sec. Because of the fact that the available X-radiation according to the above decreases only slowly with decreasing exposure time, it may be expected that photographs of simple objects which require a much smaller amount of radiation will be possible with extremely short exposure times.

Experiments which have been carried out in this direction show that this is indeed the case. As example a photograph of a hand is given in *fig. 1*. This was taken with an ordinary X-ray tube with an exposure of several millionths of a second. The fact that the

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[1]) A. Bouwers, Z. techn. Phys. **8**, 271, 1927. The formula has already been used in this periodical in connection with the discussion of the "Rotalix" X-ray tube, in the article by J. H. van der Tuuk, Philips techn. Rev. **3**, 292, 1938.

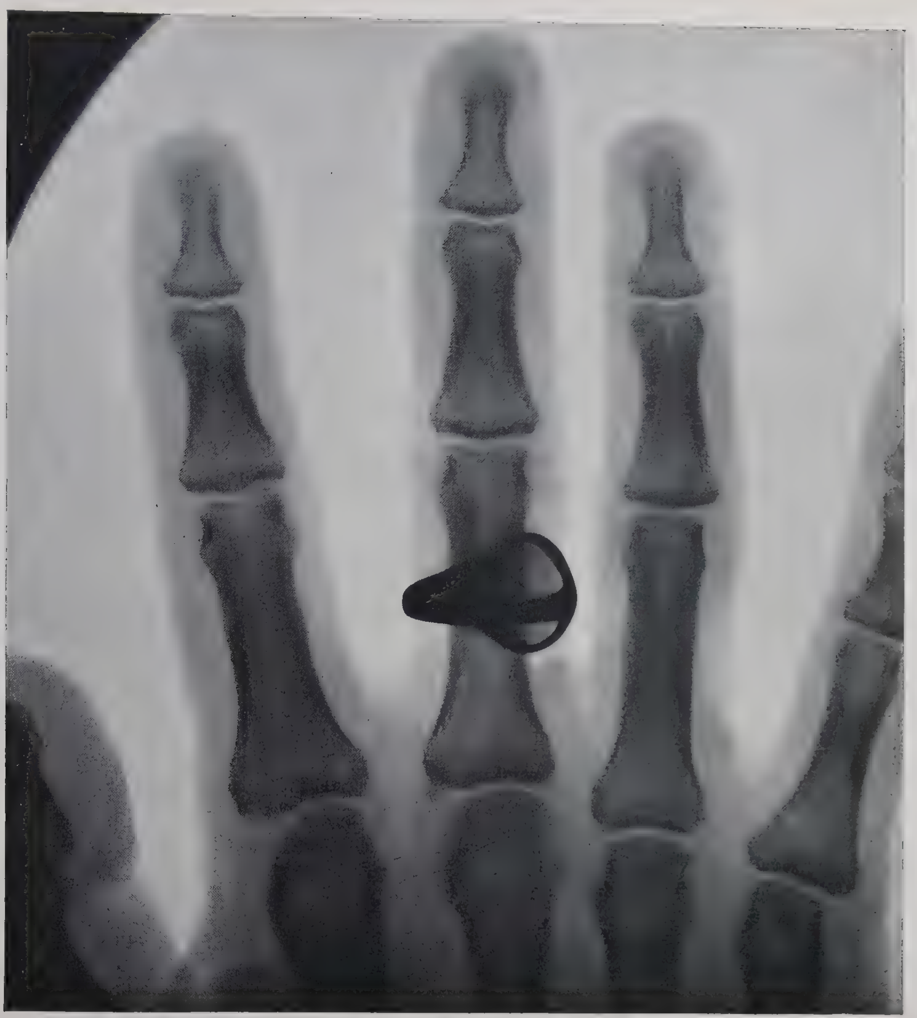

Fig. 1. X-ray photograph of a hand, taken with an ordinary X-ray tube and an exposure time of 5 × 10^{-6} sec. The bony structure is clearly visible.

photograph is by no means underexposed may be seen by the easily visible bone structure.

Description of the experiments

The X-ray tube used had a tungsten anticathode. If the appropriate values:

$$\begin{aligned} T_m &= 3\,400° \text{ K} \\ k &= 1.6 \text{ watt/cm. degree,} \\ c &= 2.7 \text{ W sec/cm}^3 \text{ degree,} \end{aligned}$$

are substituted in equation (1), one finds for an exposure time $\tau = 10^{-6}$ sec. a permissible specific focus loading $W_m = 63$ kW/sq.mm. Since about 20 per cent of the energy supplied to the tube is not dissipated on the focus, but at other spots in the tube (because of secondary electron emission), the specific tube loading may have a still higher value, namely about 80 kW/sq.mm.

This extremely brief heavy loading of the X-ray tube is realized by discharging a condenser across the tube. The circuit is shown in *fig. 2*. The speed of the discharge, *i.e.* the exposure time and the tube load can be adjusted by choosing suitable values for the capacity of the condenser and the tube current. The necessary current can easily be calculated. The focus of the X-ray tube used for the experiments was 8 mm long and 3 mm

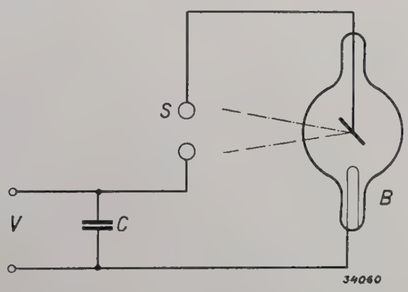

Fig. 2. Circuit diagram for taking "X-ray snapshots". The condenser *C* is charged by the high voltage source *V*. At a certain optional value of the voltage the spark gap *S* breaks down and the condenser is discharged very rapidly across the X-ray tube *B*.

wide [2]). From this in the case where $\tau = 10^{-6}$ sec. the value of 80 × 24 = about 2 000 kW for the total permissible tube load follows, *i.e.* a current of 20 A with a tube voltage of 100 kV. Such great emission currents can be obtained by temporarily increasing the saturation current of the hot cathode by strong overheating. In the experiments the X-ray tube was provided with a hot cathode such as is used in the "Rotalix" X-ray tubes. The arrangements for the focussing of the beam of electrons cause only a weak electrostatic shielding of the heated filament, so that the saturation current was already reached at relatively low voltages.

In normal X-ray photography the tube current is only about 400 mA. In the case of the experiments here described where the current was 50 times as great, a certain broadening of the focus must be expected due to the mutual repulsion of the electrons in the electron beam. The fact that this broadening nevertheless has no appreciable effect may be seen from *fig. 3* where two photographs of the focus at the two different values of the current are shown side by side for comparison.

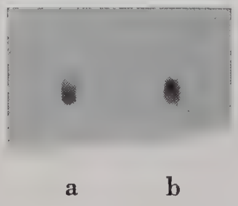

Fig. 3. Photographs in natural size of the focus of the X-ray tube. The tube has a line focus of 8 × 3 mm, which is here photographed at an angle of 13° to the surface of the anode. The photographs were obtained by allowing the X-radiation to pass through a diaphragm of 0.5 mm diameter.
a) Ordinary photograph with a tube current of 0.4 A and an exposure time of several tenths of a second.
b) Instantaneous photograph; tube current 20 A, exposure time one millionth of a second.

In the foregoing we have spoken of a certain exposure time which was tacitly assumed to be equal to the time during which the tube was loaded. When however the X-ray tube is loaded by means of the discharge of a condenser, the loading decreases with the time, and we must define more carefully the terms exposure time and loading time. The voltage on the tube decreases linearly with the time as long as we are still within the region of saturation of the cathode emission. Since the X-ray intensity is proportional to a high power of the tube voltage, we may in practice consider the exposure as concluded when the voltage has fallen to for instance 3/4 of its initial value (*fig. 4*).

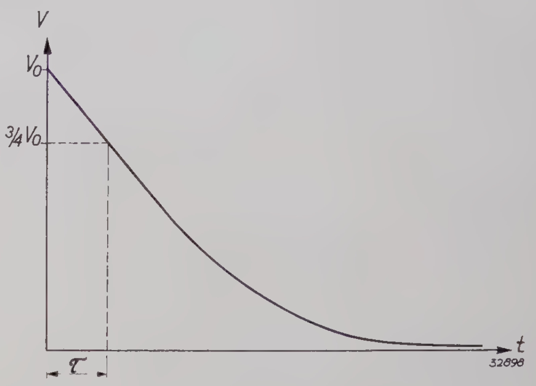

Fig. 4. Voltage V on the tube as a function of the time, during discharge of the condenser. As long as one is still in the region of saturation of the cathode emission, the voltage falls linearly, after that it falls approximately exponentially. One may consider as "effective exposure time" τ the time during which the voltage drops to 3/4 of its initial value V_0.

Similar considerations hold for the loading time: since the "tail" of the condenser discharge contributes much less to the increase in temperature of the focus, and also since the heat conduction toward the inside of the anode takes place very quickly due to the high temperature gradient, the temperature of the focus will no longer increase after a given time which we shall call the "effective loading time". This effective loading time will be of about the same magnitude as the above "effective exposure time". Equation (1) may therefore again be applied if one takes for the specific focus loading a value corresponding to an average

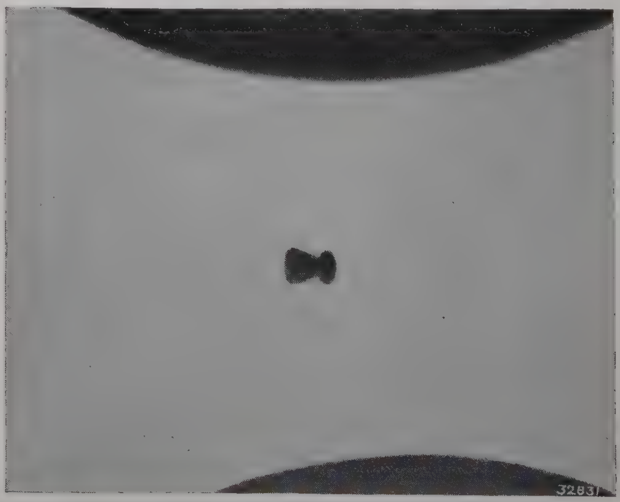

Fig. 5. Photograph of a bullet shot between the two spheres of the spark gap (5 in fig. 2). The bullet had a velocity of 200 m/sec., the exposure time was 1.5×10^{-6} sec. Further details: capacity of the condenser 0.01 μF, maximum voltage 100 kV, maximum current 20 A. The X-ray tube is hereby loaded with 1800 kW.

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[2]) For the exposure an oblique projection of such a "line focus" is used, whereby the "brightness" of the source of radiation is considerably increased. This is explained at length in the article by J. F. de Graaf and W. J. Oosterkamp. An X-ray tube for the analysis of crystal structure, Philips techn. Rev. **3**, 259, 1938.

value in the first section of the voltage drop in the curve of fig. 4.

In fig. 1 a photograph of a hand has already been shown which was taken as an X-ray snapshot in the way described above. It is obvious that the sphere of application of such instantaneous photographs will be the photography of very rapidly moving objects. In *fig.* 5 for example a photograph is given of a bullet shot from a gun taken in the above-described way. The bullet had a velocity of 200 m/sec., the effective exposure time was 1.5×10^{-6} sec. This time is short enough, because the lack of sharpness due to the motion, 0.3 mm, is still less than the lack of sharpness caused by the intensifying screens (0.4 mm). In order to obtain the exposure at the moment when the bullet was passing the field, a spark gap was used as high voltage switch. The spheres were placed at such a distance apart that the spark potential is just not reached at the voltage to which the condenser is charged. By dropping a metal object between the spheres, or by shooting the bullet to be photographed between them, the spark discharge is started and the condenser is discharged. With the X-radiation produced the spark gap is photographed, so that the bullet is captured on the photograph. After the exposure, details of which are given under the figure, the anticathode was examined. No traces of overheating were found [3]).

Cinematographic X-ray photographs can also be taken in this way. As an example we may mention the photography of the drops of metal being transferred during the process of welding [4]). The number of exposures which can be made per second in this way is limited only by the charging time of the condenser, and by the condition that the focus must have sufficient time to cool between two successive loads. A rate of several hundred pictures per second is easily attained.

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[3]) With the same purpose in view other workers have followed quite a different method (Kingdom and Tanis Phys. Rev. **53**, 128, 1938; Steenbeck, Wiss. Veröff. Siemenswerke **17**, 363, 1938). They constructed a special X-ray tube in which the anode consisted of a pool of mercury. In this case the focus can be strongly overheated if desired since the surface is always restored. In Steenbeck's experiments he estimated a temperature of 100 000° K at the focus, so that he employed much higher specific focus loading than we have used. The total X-ray energy obtainable here is however limited by the fact that the cloud of vapour given off by the anode causes breakdown, *i.e.* a decay of the tube voltage. The higher the load the sooner breakdown occurs, and with it the conclusion of the loading period.

[4]) J. Sack, Philips techn. Rev. **1**, 26, 1936; **2**, 138, 1937; **4**, 9, 1939. The photographs in these articles were however taken with much longer exposure times.

THE INVESTIGATION OF RAPIDLY CHANGING MECHANICAL STRESSES WITH THE CATHODE RAY OSCILLOGRAPH

by S. L. de BRUIN.

621.317.755 : 620.178.5

By means of a specially made resistance strip which is firmly fastened to a part of the structure to be investigated, the changes in shape caused in the structure by rapidly changing mechanical stresses are converted into electrical voltage variations. These latter can then be made visible by means of a cathode ray oscillograph. The very sensitive, portable cathode ray oscillograph type GM 3 152 can be used in this way as a quick-reaction indicator in the study of certain mechanical problems.

Mechanical stresses which occur in materials and parts of mechanical structures can be investigated by measuring the accompanying changes in shape. These changes are usually only extremely small, but they may nevertheless be investigated with special instruments constructed for that purpose. Such instruments, however, generally have too much inertia to allow the measurement of small, rapidly changing mechanical deformations, such for example as occur upon vibration in steel girder structures, high speed turbine shafts, aeroplane wings, etc. Moreover, the parts of the structure which must be tested are often difficult to reach, so that mechanical instruments can not be brought to bear.

A solution of this difficulty is offered in the possibility of replacing the mechanical measurement by an electrical one in which one may take immediate advantage of the already highly developed electrical measuring technique. It is for example possible in this way to use a cathode ray oscillograph ¹) as a very sensitive indicator with almost no inertia.

For this purpose a simple method has been worked out whereby the mechanical deformation in a structural element can be converted into variations in voltage. A specially constructed resistance strip whose electrical resistance varies practically linearly with its length is firmly attached to the outer surface of the part of some mechanical structure to be investigated. By an appropriate electrical circuit the changes in resistance are converted into changes in voltage which can be made visible directly on the screen of a cathode ray oscillograph. In order to obtain reproducible results, it is very important to take care that the resistance strip is attached as firmly as possible to the surface of the structural element being tested, so that one may be sure that the strip in its entirety undergoes the rapidly alternating expansions and contractions.

The resistance strip

The measuring strip consists of a piece of flexible insulation material (*fig. 1*), upon which a line is drawn with a suspension of powdered charcoal.

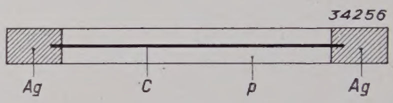

Fig. 1. Sketch of a resistance strip made of flexible insulation material (*p*) and provided with conducting silver ends (*Ag*). *C* is the carbon line whose resistance changes upon stretching or contraction.

The electrical resistance of this carbon line changes as the strip is stretched or shortened, because of the fact that the mutual contact of the carbon particles in it becomes poorer or better as the case may be. Just as in the case of the carbon microphone, where use is made of the fact that the resistance of a mass of carbon powder depends upon the pressure exerted upon it, we can employ this phenomenon in order to measure the deformations to which a mechanical construction is subjected at different conditions of loading. The great sensitivity of this method of measurement may be convincingly demonstrated by a very simple test. If the measuring strip is included in a sufficiently accurate resistance meter, a measuring bridge for example, and if the strip is then bent with the carbon line on the convex side of the resulting curve, so that it is stretched, the resistance is actually found to have increased compared with that in the non-deformed state. If the strip is bent so that the carbon line is on the inner, concave side, the resistance becomes smaller.

The resistance strip is prepared in the following way ²). On a strip of insulation material 0.3 mm thick, 50 mm long and 8 mm wide (see fig. 1), between the ends, which have been rendered conducting by means of a layer of silver, a line is drawn with a drawing pen, using very finely divided carbon powder suspended in a liquid

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¹) For instance the cathode ray oscillograph GM 3 152 which is described in Philips techn. Rev. **4**, 198, 1939 and the employment of which in mechanical engineering is discussed in Ingenieur **54**, W 29, 5 May 1939.

²) The necessary components bear the type number GM 4 470.

binder. The binder is dried by heating. A strip is obtained in this way with a resistance of for instance about 10 000 ohms.

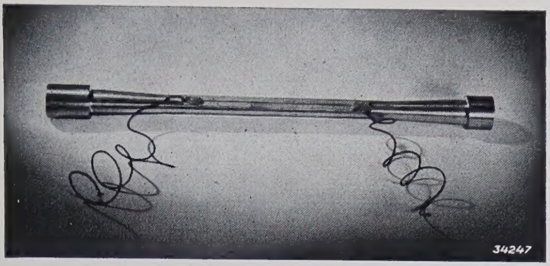

Fig. 2. Tie rod to which a resistance strip is fastened.

The resistance strip can easily be cemented to the surface of the object to be examined, for instance a tie rod (*fig. 2*) by means of celluloid lacquer. According as the temperature of the object tested is higher or lower the strip glued to it must be dried under pressure for $^1/_2$ to 1 hour. The copper wires, by means of which the strip can be included in an electrical circuit, are then fastened to the silvered ends of the resistance strip by means of a cement containing highly conducting metal. Finally, to avoid the absorption of moisture from the atmosphere, it is advisable to cover the whole resistance strip with a layer of celluloid lacquer before the measurements are begun.

Connections and sensitivity of the measuring arrangement

The resistance strip, prepared as described in the preceding section, is included in an electric circuit as indicated in the diagram of *fig. 3*. With a sufficiently high series resistance R_v, the voltage variations between the terminals of the measuring strip R_w, which is in parallel with the built-in amplifier of the cathode ray oscillograph giving an amplification of about 1 500 times, are in the first instance practically proportional to the resistance variations of the measuring strip. When the deformations are not too great, 0.05 per cent at the most, for instance, these resistance variations are also approximately proportional to the deformations, and the latter in turn, according to Hooke's law, are proportional to the mechanical stresses which cause them in the material tested. We therefore obtain as result a deviation on the fluorescent screen of the cathode ray tube which is practically proportional to the mechanical tensile stress to be measured.

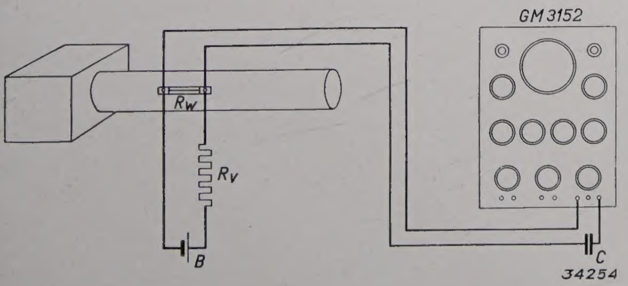

Fig. 3. Measuring arrangement with the cathode ray oscillograph 3 152. R_w is the resistance strip, R_v a series resistance, B a battery and C a condenser which serves to prevent direct current from passing through the oscillograph.

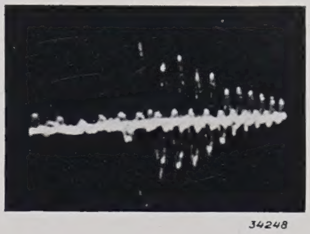

Fig. 4. Oscillogram of the variation with time of the mechanical tension in the outermost layers of a rod clamped at one end which is struck at a given moment and then allowed to come to rest unhindered.

Thanks to this proportionality it is possible to judge the vibration phenomenon to be investigated directly from the fluorescent screen of the oscillograph. As an example an oscillogram is reproduced in *fig. 4* which shows the change of tension with time for a rod clamped at one end which is set vibrating at a given moment and then allowed to return to rest without interference.

If it is desired to measure the mechanical deformations in absolute values, the relation between the change in resistance and the change in length of the measuring strip must be established by calibration. For this purpose a resistance strip is glued to a tie rod for instance (fig. 2) and included in a

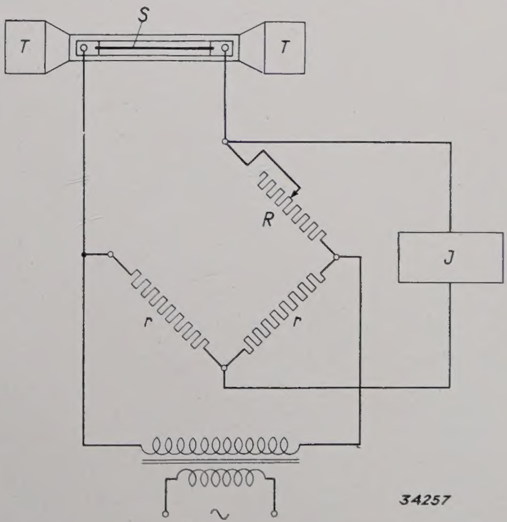

Fig. 5. Circuit of an electrical measuring bridge with which the resistance strip can be calibrated. T tie rod, S resistance strip, R resistance box, r fixed comparison resistances, J pentode amplifier with a tuning indicator.

bridge circuit [3]) as in *fig. 5*. The tie rod can then be stretched in a machine for testing tensile strength (*fig. 6*).

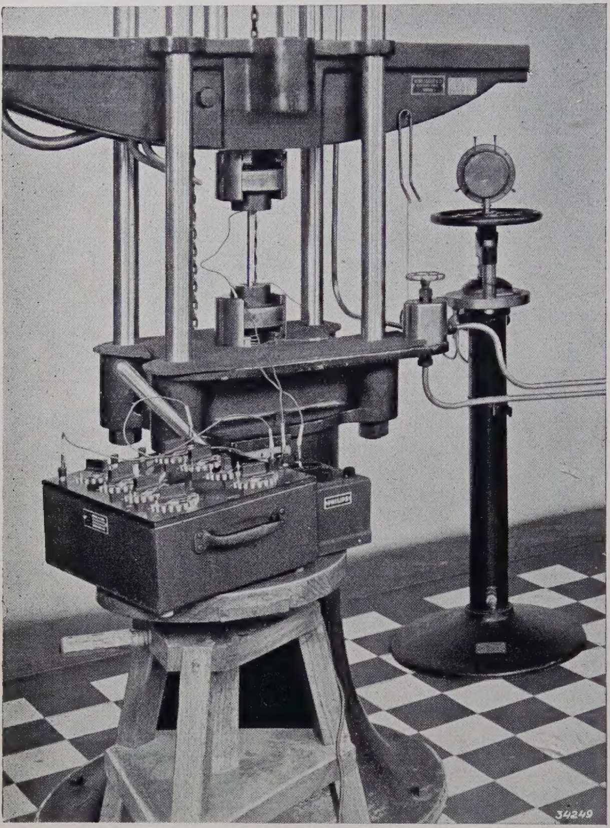

Fig. 6. Measuring arrangement for the calibration with the help of a machine for testing tensile strength.

Between the specific change in resistance of the measuring strip and the specific change in length ϱ of the tie rod, measured with the above-mentioned machine, a satisfactorily reproducible [4]) relation can be found of a character such as that shown in curves *I*, *II* and *III* of *fig. 7* which were determined with several test objects. It may be seen from this that for deformations ϱ of not more than 0.03 per cent, the relation between the variation of electrical resistance λ and mechanical tension is in fact practically linear. In this region the quotient λ/ϱ has a value of about 15. With larger deformations the electrical resistance is found to increase more rapidly than proportional to the stretch.

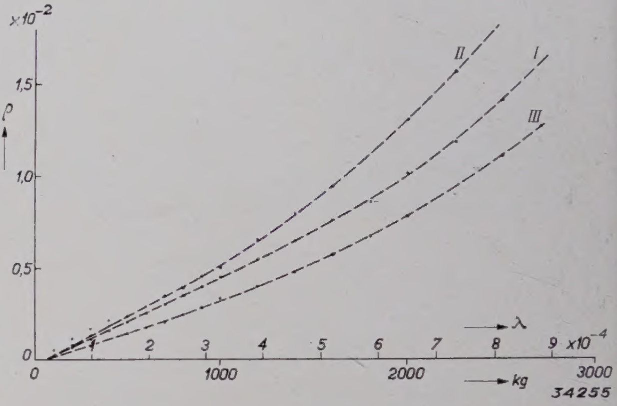

Fig. 7. Relation between the specific resistance variation ϱ of the measuring strip and the load on the tie rod in kg, or the specific stretch λ of this tie rod.

For the calibration of the measuring strip it is by no means necessary that one use a machine for testing tensile strength, it is only necessary to be able in some way or other to cause an accurately measurable change in length of the strip. In order to test a strip it may for instance be glued to a test rod (*fig. 8*) which is supported at two points at a distance $2\,l$ from each other. The rod is then bent between its points of support into a circular form over a distance *d*. The changes in length of the upper and lower surfaces of the rod then follow from the formulae for the circle. In this way the specific change in length of the rod can be determined and the relation between that and the specific change in resistance of the strip, measured in bridge connection, can be found.

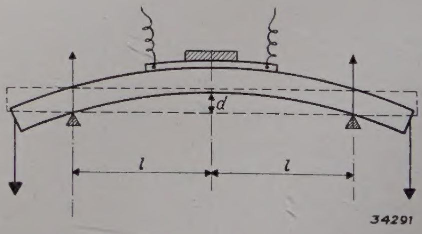

Fig. 8. Circularly bent test rod, supported at two points at a distance apart of 2*l* and with a bend of *d*.

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[3]) For example the "Philoscope", type GM 4 140 which was discussed in Philips techn. Rev. **2**, 270, 1937.

[4]) For reproducibility it is necessary, as is usual in stretching tests, that the rod should have been prestretched.